Reading Skills after Cochlear Implantation

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Reading Skills after Cochlear Implantation

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Contents

Chapter 1 ● **Introduction**

This study aimed to investigate how the use of a cochlear implant affected reading comprehension. Comparisons were made of reading comprehension abilities between profoundly deaf children with cochlear implants, deaf children without cochlear implants and children with normal hearing. Furthermore, we tested the hypothesis that enhanced auditory speech perception skills and improved language skills after cochlear implantation would have positive effects on the reading comprehension of profoundly deaf children. Paragraph 1.1 introduces the rationale and aims of the study. Paragraph 1.2 describes the group of profoundly deaf children with cochlear implants, as well as the two reference groups that are studied: deaf children without cochlear implants and children with normal hearing. Paragraph 1.3 explains the method of data collection.

1.1 Rationale and aims

A cochlear implant enables speech perception in profoundly deaf children who were unable to perceive speech via audition with conventional hearing aids. In profoundly deaf persons, cochlear implants (CIs) generally provide better auditory input, that is, lower auditory thresholds in a broader frequency range, than conventional hearing aids do. Cochlear implants work differently from conventional acoustic hearing aids that simply amplify acoustic signals that still have to be processed by the (damaged) cochlea. In contrast, the speech processor of a cochlear implant codes speech signals into electrical stimuli and then transfers them directly to the auditory nerve endings in the cochlea, thus bypassing the auditory sensory organ. Since the FDA approval of multi-channel CIs in children in the USA (1990), cochlear implantation gradually has become a regular worldwide part of hearing rehabilitation in profoundly and severely deaf children.

In the Netherlands, these devices and rehabilitation have only been financed by the national health insurance companies since 2001. Although CIs offered remarkable technical opportunities, their introduction did not go undisputed in the Netherlands. The Deaf Community opposed the Cochlear Implant teams in their medical-technical approach to deafness in children (Blume, 2000; Wever, Oderwald, Van Leeuwen, & Van den Broek, 1998). Viewing deafness as a sensory deficit was in conflict with the emerging emancipation of the ideologies of the Dutch Deaf Culture. The start of cochlear implantation coincided with the efforts of the Deaf Community to obtain official recognition of Sign Language of the Netherlands (SLN) as language for persons with pre-lingual deafness. Blume (2006) described the views (and fears) of the Deaf Community and of parent organizations at that time. He claimed that oralism offered little to deaf persons compared to the benefits of sign language and the Deaf Culture. Cochlear implantation focused on audition, development of spoken language and mainstream education and implicitly aimed to normalize deaf children, as opposed to valuing the (cultural) diversity that deafness can bring. One of the important issues is the friction between the responsibility towards a child’s development and the responsibility towards a medical technique or a culture. Despite the different views, the opinions of the proponents and opponents of CIs in children did *not* collide in the Netherlands as they did in many other countries. In 1995, a national platform was established to formalize the dialogue between organizations for the deaf and the Cochlear Implant teams of Nijmegen and Utrecht.

In the early 1990s Sign Supported Dutch was used in most services for young deaf children and their parents. As was described by Wever (2002, p.183), many parents of young deaf children focused initially on establishing interaction with their child and viewed the use of signs as the most preferable method. In the meantime, the positive effects of cochlear implantation in adults had become apparent and many parents applied for implants for their young deaf children, which gave rise to waiting lists. These parents not only comprised those who had chosen an oral approach, but also those who preferred signed communication. Contrary to the expectations of the Deaf Culture and schools for the deaf, parents did not consider that the choice of a cochlear implant was in conflict with the use of sign language. The parents’ views appeared to be fairly pragmatic and their priorities and choices changed with the development of their child (Wever, 2002). Wever found that the prevailing expectation of the parents who applied for an implant for their child was the improvement of (auditory) environmental awareness. However, the desire to enhance access to the development of spoken language was their main hope. In many children cochlear implantation did indeed lead to substantial improvement in auditory speech perception and it provided access to spoken language. However, Dutch schools for the deaf have been employing a bi-lingual approach since 1999, with a dominant position for SLN. The parents of the children with CIs felt that their children were underestimated and under-challenged in these educational settings, i.e. the potential of each individual was being ignored (Wever, 2002). (This was also a matter of concern to many parents of non-implanted children in deaf education, it should be added.) A protective school environment and the use of SLN were initially seen as advantages of deaf education. Later, when auditory access to spoken language became a realistic option, these issues were valued less by these parents. Parents who requested more spoken language for their children found that most schools were fairly inflexible in their attitude towards the use of spoken language. These parents therefore tended to choose between mainstream education and schools for the hard-of-hearing/language impaired children. However, the parents were not rejecting the use of signs at all. Data on 200 Dutch children (Vermeulen, Van den Broek & Langereis, 2005) showed that within 2 years after implantation the percentage of children in mainstream education increased from 5% to 33%. The percentage of younger children who were not at special schools for the deaf increased from 18% to 59% within two years after implantation. It is important to note that the teachers and the implant centres did not necessarily consider mainstream education to be the best setting for each of these children. So, 20 years after the introduction of CIs in the Netherlands (in 1986), the question re-emerged about the most appropriate communication mode and educational setting for children with better speech perception skills.

We can conclude that the benefit derived from the use of CIs by many profoundly deaf children poses new challenges to the upbringing and education of these children. Whereas after the introduction of CIs, expectations initially focused on the auditory detection of environmental sounds, now the long-term developments that stretch beyond these first expectations are gradually becoming apparent. (See for an overview Geers, 2006 and Marschark, 2007.)

First, reports were published on improvements in auditory speech perception abilities after cochlear implantation in profoundly deaf children (e.g., Geers, Brenner, & Davidson, 2003; Meyer, Svirsky, Kirk, & Miyamoto, 1998; Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004; Svirsky, Teoh, & Neuburger, 2004). Children with implants showed auditory speech perception skills that were comparable with those of severely hearing impaired children with conventional hearing aids (Snik, Vermeulen, Brokx, Beijk, & Van den Broek, 1997). Then it was found that CIs provided deaf children with auditory access to spoken language, which was reflected in increased (spoken) vocabulary (Connor, Graig, Raudenbush, Heavner, & Zwolan, 2006; Damen, Langereis, Snik, Chute, Mylanus, 2007; Geers, Nicholas, & Sedey, 2003; Myamoto, Houston, Kirk, Perdew, & Svirsky, 2003; Vermeulen, Hoekstra, Brokx, & Van den Broek, 1999; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). Furthermore, Spencer, Tye-Murray and Tomblin (1998) and Svirsky, Stallings, Lento, Ying and Leonard (2002) reported positive effects of audition on the development of morphological skills. Deaf children with CIs who had better auditory speech perception skills also had better narrative skills. These narrative skills had a positive association with reading comprehension (Crosson & Geers, 2001; Vandenboorn, Langereis, Jansonius & Knoors, 2006).

After it had become well-established that cochlear implantation had positive effects on speech perception and spoken language development, a subsequent focus of research was on the comprehension of written language. The ability to read is of enormous importance to educational attainment and participation in society. In deaf adults, the generally reported low literacy levels proved to be a reason for underemployment (MacLeod-Gallinger, 1992). Previous research has shown that deaf children without CIs have difficulty with the comprehension of written text (e.g., Holt, 1993; Holt, Traxler & Allen, 1996; Traxler, 2000). Reading comprehension in deaf Dutch children without CIs lagged substantially behind that of hearing their peers with normal hearing (Wauters, van Bon & Tellings, 2006). Reading difficulties in deaf children are generally attributed to inefficient decoding and limited spoken language skills. In children with normal hearing decoding is based on the perception and analysis of spoken language that enables them to use letter-to-sound correspondence and they represent the written text as a phonological code during reading. In profoundly deaf children without implants, access to phonology is blocked. Cochlear implants improve auditory speech perception to such a level that speech can be perceived via audition only. In deaf children without CIs, the decoding problems evidently cause reading difficulties, but their difficulties with reading can also stem from disabilities in other (spoken) language components, such as vocabulary and morpho-syntax (De Jong & Van der Leij, 2002; Marschark & Harris, 1996; Merrills, Underwood & Wood, 1994; Musselman, 2000; Paul, 2003). As was stated by Perfetti and Sandak (2000), the process of reading builds on spoken language that provides the basis of the writing system. Cochlear implantation has positive effects on spoken language skills. Therefore it is expected that that reading comprehension will be enhanced via improved language skills rather than via decoding alone.

The topic of this study was to elucidate potential benefit of a cochlear implant on the reading comprehension in profoundly deaf children. A few studies addressed reading comprehension in deaf children with CIs and reported better outcomes than those in deaf children with conventional hearing aids (Connor & Zwolan, 2004; Geers, 2003; Spencer, Barker & Tomblin, 2003; Spencer, Gantz, Knutson, 2004). Although it is plausible that improved reading skills are a consequence of the use of a cochlear implant, there is no direct evidence of an association of reading comprehension with auditory speech perception skills. In this study, we investigated some links in that hypothesized causal chain. Firstly, we analysed the influence of two components of reading comprehension, defined by the Simple View of Reading model (Hoover and Gough, 1990): decoding and language comprehension. Secondly, we studied the relation between post-implant auditory speech perception and language development. Thirdly, we investigated the interrelations between post-implant auditory speech perception, language skills and reading comprehension. These issues are described in the three empirical chapters, 2, 3 and 4. In Chapter 2, we compared the reading comprehension of profoundly deaf children with CIs to the reference data on deaf Dutch children without CIs (Wauters et al., 2006). Next, we compared the reading comprehension of the two deaf groups (with CIs and the reference data of children without CIs) to that of the children with normal hearing. Then we investigated decoding (the first component of reading comprehension defined by the Simple View of Reading model) using a visual word recognition task. Again, we compared the decoding skill of our children with CIs to that of Wauters' children without CIs and that of hearing peers (Wauters et al., 2006). In the next step, we investigated the extent to which differences in decoding between the two deaf groups (with and without CIs) influenced reading comprehension. In Chapter 3, we followed the development of auditory speech perception and language comprehension (the second component of reading comprehension defined by the Simple View of Reading model) after cochlear implantation and explored the associations with reading skills. We also investigated the relation between auditory speech perception and language skills. In Chapter 4, we used Structural Equation Modelling to evaluate a causal model that specified the effect of post-implant auditory speech perception on reading comprehension, via language skills. We also studied the influence of child and environmental characteristics on these specified relations. In Chapter 5, we present an overview of the study, the discussion and conclusion.

1.2 The study groups: description of participants

In the three empirical chapters the results are based on one group of profoundly deaf children with CIs (DCI group) and two reference groups: one group of deaf children without CIs (D group) and several groups of children with normal hearing (H groups). Relevant data of these subject and reference groups are described below.

Deaf children with Cochlear Implants (DCI group)

The 'experimental group' comprised the first 50 profoundly deaf children and adolescents who have received an implant since the start of the Nijmegen Paediatric Cochlear Implant programme in 1990 and who met the following inclusion criteria: a minimum of 3 years of implant use, at least 7 years of age, age at onset of deafness younger than 6 years, full insertion of the electrode array, absence of learning disorders and participation of their school in the test procedure. Table 1 shows the inclusion criteria and the numbers of children who were included or excluded accordingly.

TABLE 1

Inclusion criteria and the numbers of children who were excluded and included accordingly

Inclusion criterion	Number excluded	Number included
3 yrs CI experience	-	81
More than 7 years old	14	67
Onset of deafness before the age of 6 years	2	65
Participation of school in test procedure	2	63
Willingness to participate (age 16+)	3	60
Capable of performing reading task	2	58
No learning disorder	2	56
Full insertion of electrode array	6	50

Children were only included if they were able to perform the task according to their teacher. At the time of testing, 81 children met the inclusion criterion of at least 3 years of implant use and 50 of them met all the other criteria,[1] and were included in the study. All children were using Cochlear Nucleus cochlear implant systems. M-PEAK (Multi-peak) speech-coding strategies,[2] were being used by 15 children up to the time of the reading tests. The other children had been using a more sophisticated strategy, SPEAK (Spectral-peak) since the initial fitting of the device. The Deaf Cochlear Implant group (DCI group) comprised 25 girls and 25 boys. All of the children had parents with normal hearing. The children were residing and going to schools throughout the Netherlands. Before implantation, 37 children were educated at schools for the deaf, 11 at schools for the hard-of-hearing and 2 at regular schools (mainstream education). One of the six Dutch schools for the deaf that participated in this study was using an aural/oral approach. In 1999, a bilingual approach was adopted at all the schools for the deaf (with varying proportions of Sign Language of the Netherlands, Sign Supported Dutch and spoken language). At schools for the hard-of-hearing the mode of communication was generally Sign Supported Dutch. By the time we made our reading assessment, 24 children were at 24 different mainstream schools, 9 children were at schools for the hard-of-hearing and 17 children were at schools for the deaf. Tables 2 and 3 show the aetiological and audiological characteristics of the participants. There was wide variability in these characteristics. More than half of the DCI group had acquired deafness whose onset lay within the first few years after birth, whereas in 18 children the onset of deafness was before birth. In forty-five children the deafness was pre-lingual (before the age of 36 months). Note the long mean duration of auditory deprivation (Table 3), which was partly the consequence of the inclusion of children with Usher's Syndrome Type I b (congenital very profound deafness and progressive retinitis pigmentosa), who received a cochlear implant at a relatively old chronological age. These relatively older children were expected to have limited auditory speech perception abilities after cochlear implantation, due to the long period of deafness (e.g. Snik, Makhdoum, Vermeulen, Brokx & Van den Broek, 1997).

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1 We excluded children who had severe medical problems or had moved abroad.

2 The speech signal is processed by the speech processor by means of speech coding strategies. For example M-PEAK extracts the speech features F0, F1 and F2 and adds a high frequency band. SPEAK does not extract features but analyses the speech signal in 20 frequency bands (Lamoré & Vermeulen, 2000).

TABLE 2

Aetiological data

Aetiology	*N*				
Congenital	18	Hereditary	12	Usher	6
				Waardenburg	2
				Other	4
		Infection	3	Cytomegaly (CMV)	2
				Rubella	1
		Anomaly	3	Enlarged Vestibular Aquaduct (EVA)	2
				Mondini	1
Unknown	12				
Acquired	20			Meningitis	20

Owing to their progressive visual handicap they received a cochlear implant, in order to be able to facilitate auditory contact with the environment. In the profoundly deaf children in the DCI group the mean unaided Pure Tone Average (PTA),[3] in the best ear was poor and showed that these children had little or no access to the auditory perception of speech. After cochlear implantation, their auditory sound detection thresholds improved remarkably, as was shown by the mean PTA with the cochlear implant. For the purpose of indicating the effect of cochlear implant use on auditory speech perception, the equivalent hearing loss values (EHL) in the DCI group are also shown in Table 3. The EHL (in dB) expresses the auditory speech recognition skill in comparison with that in deaf children who are using conventional hearing aids (Snik, Vermeulen, Brokx, et al., 1997). Before implantation, the speech recognition skills of the DCI group were at the EHL level of that of profoundly deaf children, as was expected. After implantation, their auditory speech perception skills were in the same range as those of hard-of-hearing children fitted with conventional hearing aids, who had 80 dB hearing loss. This indicates that their CIs were functioning effectively.

3 The pure tone average expresses the average loss in dB HL at 500, 1000 and 2000 Hz. In the unaided condition, measurements were carried out with a maximum gain of 125 dB. If no tone detection was possible, values of 100, 125 and 125 dB were used in the computations of the unaided PTA. In the computations of the aided PTA, values of 80, 100 and 100 dB were used, respectively.

TABLE 3

Audiological characteristics and chronological age at reading assessment

Characteristic	*M*	*SD*	min	Max
Age at onset of deafness * (months)	13	19	0	72
Duration of auditory deprivation (months)	61	29	16	140
Age at implantation (months)	74	28	27	146
Pure Tone Average unaided (pre-implant) (dB)	119	6	110	>125
Pure Tone Average with hearing aid (pre-implant) (dB)	87	8	75	>100
Pure Tone Average with cochlear implant (dB)	50	4	40	70
Equivalent hearing loss pre-implant (dB)	121	5.6	110	128
Equivalent hearing loss 3 years post-implant (dB)	81	12.6	70	110
Chronological age at reading assessment (months)	153	43	87	271

* Two children with progressive hearing loss were excluded from these computations, because the exact time of onset of profound deafness was unknown. The diagnosis of severe hearing loss had been confirmed before the age of six years.

Our study population of children with implants does not represent the present population who receive CIs nowadays. The *clinical* criteria for implantation applied in the 1990s differed from the ones used now. At present, not only children with profound deafness are implant candidates, but also those with severe hearing loss. Furthermore, the duration of deafness is kept as short as possible. The children in our group all had profound hearing loss and the duration of deafness prior to implantation was relatively long, especially in the congenitally deaf children. Some of our children were using an older type of device (22 channels) that had been programmed for a long period with M-PEAK speech-coding strategies, whereas the present CI systems are more sophisticated. An advantage of the heterogeneity of our group was that it enabled investigation of the role of these variables. Associations between the different variables might be identified especially in view of the relatively slow development and the variability in performance as a consequence of the inclusion of children with fairly unfavourable conditions.

Deaf children without cochlear implants (D group)

We were kindly permitted to use the data on reading comprehension and visual word recognition from deaf children without CIs, collected and analysed by Wauters (2005).The

504 deaf participants without CIs included almost all of the deaf children and adolescents in the Netherlands. Detailed results on this D group were described by Wauters et al. (2006). There were 235 girls and 269 boys; both the parents of 466 children had normal hearing. Deafness was pre-lingual in 452 children. The average unaided PTA in the D group was 108 dB (range from 80 to 140 dB). Not all the children in this group were using (conventional) hearing aids and data on the thresholds with conventional hearing aids were not available. Children with additional handicaps or learning disabilities had been excluded from this group. A total of 423 children were receiving special education for deaf children, 46 were receiving education at special schools for the hard-of-hearing and 35 children were in mainstream settings. Comparability of the subject characteristics in the two samples of deaf children (one with CIs and one without) is discussed in more detail in the Results section.
Reference data on equivalent hearing loss in children with conventional hearing aids (Paragraph 3.3) have been described by Snik (Snik, Vermeulen, Brokx, et al., 1997; Snik, Vermeulen, Geelen, Brokx, & Van den Broek, 1997). Other reference data comprised norm data from hearing children or from deaf children without CIs that are available in the test manuals.

Hearing children (H group)

We used data on visual word recognition obtained from 1475 children with normal hearing who were receiving mainstream education. They were tested within the framework of the study by Wauters et al. (2006). The sample had a mean age of 10;1 years and contained about equal proportions of boys and girls.

1.3 Method

Data were collected within the framework of the structural follow-up in the clinical implant programme. Furthermore, assessments were carried out specifically for research purposes. In the present section, the aspects that were evaluated and the timing of the assessments are briefly described. Detailed information about the test instruments, rationales, interpretation of the scores, the assessments and evaluation times are described in the relevant chapters.

TABLE 4

Overview of data/tests, sources of data on the experimental group (DCI) and reference groups (D = deaf without CI, H = hearing), and the time during follow-up, with a reference to the relevant chapter

Data/test	Data collection Source	Group (reference or norm data)	Time during follow-up	Test/source described in Chapter
Aetiological factors	CI protocol	DCI	Pre-implant	1
		D and H		2
Anamnesis data	CI protocol	DCI	Pre-plant 12, 24, 36 months post-implant and in 2002	1
Environmental factors	CI protocol	DCI	Pre-implant 12, 24, 36 months post-implant and in 2002	3
Audiological factors	CI protocol	DCI	Pre-implant 12, 24, 36 months post-implant and in 2002	3
Reading comprehension	This study At school	DCI	Post-implant, in 2002	2
		H test manual D Wauters		
Visual word identification (decoding)	This study At school		Post-implant, in 2002	2
		H Wauters D Wauters		
Auditory speech perception	CI protocol	DCI	Pre-implant 12, 24, 36 months post-implant	3
		D Snik		
Auditory consonant discrimination	This study At CIC	DCI	Post-implant, between 2001 and 2002	3
Phonological knowledge	This study At CIC	DCI	Post-implant, between 2001 and 2002	3
Receptive vocabulary	CI protocol	DCI	Pre-implant 12, 24, 36 months post-implant	3
		H test manual		
Morpho-syntactic skills	This study At school	DCI	Post-implant, in 2002	3
		D test manual		

Table 4 gives an overview of data sources, the groups who were tested and the time of administration during follow-up. Furthermore, the chapters are indicated in which the tests and results are described in more detail. The advantage of using data collected for clinical evaluation was that children and parents did not have to be burdened with extra assessments. A limitation of the use of these data was that the test battery and evaluation times were fixed and could not be influenced. We obtained permission to use the anamnestic data and previous test results from all the parents. These anamnestic data concerned aetiological, medical, social and educational topics. Other relevant data collected in the clinical evaluation included the audiological thresholds, auditory speech perception scores and receptive vocabulary scores. Auditory thresholds were determined prior to implantation with and without conventional hearing aids and at approximately six weeks after implantation.

The latter thresholds were used to quantify post-implant outcomes. Auditory speech perception tests and receptive vocabulary tests were administered pre-implant with the use of appropriate conventional hearing aids and post-implant at yearly intervals, i.e. 12, 24 and 36 months after implantation. In Table 4, the source of these data is indicted as ‘CI protocol’. For the specific purpose of the present research, five additional tests were administered to the children. Some of these tests were developed within the framework of this study (see Table 4, “this study”). Assessments were carried out in 2001 and/or 2002. Duration of implant use at that time varied between 3 and 11 years. Three tests were administered at the child’s school: a reading comprehension test, two lexical decision tasks (to assess decoding skill) and a written language test for deaf children (to evaluate morpho-syntactic competence). Appropriate test levels were chosen on the basis of information from the teacher about the grade of the child and the expected language and reading level. Assessments were made at 35 schools. One school for the deaf was unable to participate, which meant that two children had to be excluded. Tests were administered at the schools according to a set protocol and supervised by a teacher or peripatetic teacher. Two tests that were developed specifically for this research were administered in a second session between 2001 and 2002: an auditory consonant discrimination task and a lexical decision task (to assess phonological text decoding skill).

Chapter 2 ● **Reading comprehension in deaf children with cochlear implants**[1]

The reading comprehension and visual word recognition in 50 deaf children and adolescents with at least 3 years of cochlear implant use were evaluated. Their skills were contrasted with reference data of 500 deaf children without cochlear implants (CIs). The reading comprehension level in children with CIs was expected to surpass that in deaf children without implants, partly via improved visual word recognition. Reading comprehension scores of children with implants were significantly better than those of deaf children without implants, although the performance in implant users was substantially lagging behind that in hearing children. Visual word recognition was better in children with CIs than in children without implants, in secondary education only. No difference in visual word recognition was found between the children with CIs and the hearing children, while deaf the children without implants showed a slightly poorer performance. The difference in reading comprehension level of the deaf children with and without CIs remained present when visual word recognition was controlled for. This indicates that other reading-related skills were also contributing to the better reading comprehension skills of deaf children with CIs.

[1] A slightly adapted version of this chapter has been published. Reference: Vermeulen, A., van Bon, W., Schreuder, R., Knoors, H., & Snik, A. Reading comprehension of children with cochlear implants. Journal of Deaf Studies and Deaf Education (2007) 12, 283-302.

2.1 Introduction

The benefit that many profoundly deaf children can derive from the use of cochlear implants,[2] poses new challenges to the upbringing and education of deaf children. Since the 1990s, growing evidence was reported of substantial increases in auditory speech perception abilities after cochlear implantation, in profoundly deaf children (e.g. Meyer et al., 1998; Robbins et al., 2004; Svirsky et al., 2004). The auditory speech perception skills of profoundly deaf children often even reached a level comparable to that of hard-of-hearing children, over the course of time (Snik, Vermeulen, Brokx, et al., 1997). Moreover, CIs proved to provide deaf children with auditory access to spoken language, reflected in increasing receptive vocabulary (Geers, Nicholas, & Sedey, 2003; Miyamoto et al., 2003; Svirsky et al., 2000; Vermeulen et al., 1999). A subsequent focus of research was the effect of cochlear implantation on written language. For enhancement of educational attainment and for full participation in the society, reading is of course extremely important. Since the process of reading depends on the spoken language that provides the basis of the writing system (Perfetti & Sandak, 2000), one expectation of CIs is that they might enhance reading comprehension of deaf children. It is on the reading skills of deaf children with CIs that our study focuses.

Knowledge of spoken language and spoken language skills contribute to reading comprehension and to visual word recognition,[3] two major components of reading competence (see below). It is clear that the development of reading in deaf children without age-appropriate spoken language skills will be difficult and slow (Musselman, 2000). Long-term research into the reading skills of deaf children and adolescents without CIs showed a limited level of reading comprehension (e.g. Holt, 1993; Holt et al., 1996; Traxler, 2000). In a recent large scale study, on the reading skills of deaf Dutch children, Wauters et al. (2006), reported that the average reading comprehension scores of deaf children and adolescents were

[2] A cochlear implant enables sound perception in profoundly deaf children who were unable to perceive speech with conventional hearing aids before. In profoundly deaf persons cochlear implants generally provide much more auditory input, in a broader frequency range, than conventional hearing aids do. A cochlear implant works in a totally different manner than conventional acoustic hearing aids, which just amplify auditory signals that still have to be processed by a damaged cochlea. The internal part of a cochlear implant transfers signals, that are already coded by a speech processor into electrical stimuli directly to the auditory nerve endings in the cochlea.

[3] The notion ‘visual’ is generally not employed in this context. We use it to distinguish the notion from auditory word recognition.

"shockingly low" (see also Wauters, 2005, p. 145). The average reading comprehension for children in the ages of 7 to 20 years was at a level of first grade of primary education.

There have been divergent results regarding the level of visual word recognition in deaf children without CIs. Harris and Beech (1998) and Merrills et al. (1994) found that deaf children had lower word identification skills than their hearing peers. Contrastingly, Burden and Campbell (1994) and Fischler (1985) did not observe any significant difference in word recognition skills between older deaf children and children with normal hearing. The different ages of the children in the studied samples may have caused this difference. Wauters et al. (2006), however, found that the mean visual word recognition scores of deaf children in primary and in secondary education were significantly lower than those of their hearing peers, though to a lesser extent than were reading comprehension scores. Furthermore, Wauters et al. found that the visual word recognition skills did not explain the poor reading comprehension scores of children without CIs. We do not know however, whether this is the case in children with CIs, because Wauters' population did not include cochlear implant users.

At present very little is known about the reading skills of deaf children with CIs. An early study on reading comprehension (Spencer, Tomblin, & Gantz, 1997) reported the results of a heterogeneous group of 40 pre-lingually profoundly deaf implant recipients. Their skills were compared with results of children without CIs, that have been reported in other studies on reading comprehension. Performance of almost half of the children with CIs was within the 8-month range of grade level performance indications that were obtained from other studies. However, there was considerable variability in the scores of the CI users. Moreover, the reference data of children without CIs in this study did not permit proper comparison with the children with CIs, because different tests had been used and the inclusion criteria of the implant group were not described. Spencer et al. (2003) conducted a study on reading comprehension in two groups of 16 children. Pre-lingually deaf children with CIs were compared to a group with normal hearing. They found significant differences between the mean standard scores for the two groups, but the ranges of the standard scores were similar. Ten out of the 16 children (63%) with implants performed within 1 *SD* of the children with normal hearing. As part of a large scale research study on data obtained from cochlear implant recipients, Geers (2003) reported on the performance and predictors of reading skill development. She found that over 50% of the deaf children with CIs performed within 1 *SD* of the mean, while 80% of the scores were within 2 *SD* of the mean. Connor and Zwolan (2004) examined multiple sources that might influence the reading comprehension skills of deaf children with implants. They reported a mean standard score of 69.8. For children implanted in their preschool ages the mean standard score was 76.4. The mean score was more than 1 *SD* below that of hearing children, even in the preschool years.

In the above-mentioned studies different tasks have been used to assess reading comprehension. Spencer et al. (2003) and Connor and Zwolan (2004) assessed reading comprehension with a cloze task. Performance levels reported by Geers (2003) were comparable with the levels reported by Spencer et al. (2003). Although they used different tasks and had children of different ages in their samples, the two studies indicate that children with CIs obtain higher reading comprehension levels than deaf children without CIs, when compared to hearing norms. They report that more than half of the children performs within the 1 *SD* range of hearing children. Their results are better than those reported by Connor and Zwolan (2004). Different child and environmental characteristics, however, are known to influence reading and reading related skills. The participants in these two studies differed, for example, regarding age at onset of deafness, age at implantation, duration of deafness until implantation, duration of implant use, age, IQ and educational setting. From the information provided, however, no conclusions can be drawn in this respect. The heterogeneity of the samples makes it different to compare the results of these studies.

For our investigation of the reading competence of deaf children with CIs we examine two major skills: text comprehension and visual word recognition. Although these skills are highly correlated in the hearing population (Aarnoutse & Van Leeuwe, 1988) they are regarded as relatively independent (e.g. Oakhill & Cain, 2000; Perfetti, 1985). Despite the fact that these skills have been found to be associated, word recognition and reading comprehension can be differentiated. Stothard and Hulme (1996) for instance, found that the causes of reading comprehension difficulties were different form ones that caused visual word recognition deficits. In addition Oakhill, Cain and Bryant (2003) described dissociation of word reading and text comprehension and the underlying abilities that account for their variance.

In their Simple View of Reading model Hoover and Gough (1990) stated that reading comprehension is the product of decoding and language comprehension. According to this model, the enhancement of auditory speech perception skills after cochlear implantation can influence reading comprehension via three routes: via decoding, via spoken language and via the contribution of visual word recognition to reading comprehension. First, decoding is an important underlying sub skill for visual word recognition and it is likely to be facilitated by better auditory speech perception. In hearing children, decoding is a process dependent on phonological abilities that pertain to the ability to detect, to store and to retrieve the basics sound elements of the spoken language (De Jong & Van der Leij, 2002). Access to auditory information will lead to the use of letter-to-sound-correspondences and thus provide a basis for phonological decoding. For deaf children who do not perceive spoken sounds via audition, decoding will be difficult. Although decoding does not uniquely rely on phonological knowledge alone (Hanson, Goodell, & Perfetti, 1991; Leybaert, 1993), auditory access to phonological information provides the most efficient way. A higher degree of hearing capacity and better speech intelligibility were found to enhance the ability of deaf children to use phonological coding (Hanson & Fowler, 1987).Therefore, cochlear implantation may lead to enhanced decoding skill because it improves the hearing level and speech intelligibility.

However, as discussed by Marschark and Harris (1996), some portion of reading difficulties can be attributed to the inability to hear the sounds of spoken-written language, but other language related components such as vocabulary and syntax influence reading skills of deaf children as well. Musselman (2000) also discussed the important role of language specific knowledge (vocabulary and syntax) in reading comprehension of deaf children. Hence, secondly, as mentioned above, auditory access to spoken language has been demonstrated to positively influence the development of receptive vocabulary. Language comprehension is one of the components of reading comprehension according to the Simple View of Reading. Tunmer and Hoover (1992) argued that, after decoding, comprehension of the discourse in principle relies on the same underlying skills, regardless of whether the discourse concerns written or spoken text. They described reading as a derived skill that builds upon spoken language, and Perfetti and Sandak (2000) found that to be the case for deaf readers. Receptive vocabulary knowledge is reported to be an important factor in reading for hearing (De Jong & Van der Leij, 2002) as well as for deaf children (Marschark & Harris, 1996). Oakhill and Cain (2000) further described the relation between oral language and reading comprehension. They reported that difficulties in storytelling and the inability to detect the structure and main point of an event are likely to be the cause of reading comprehension difficulties. There are many reports about improving receptive vocabulary,[4] morpho-syntactic and narrative skills after implantation (see Discussion section).Third, we expect visual word recognition to improve, partly based on the enhanced decoding skill based

4 When the term 'Vocabulary' is used without any further specification it refers to spoken language only.

on auditory access to phonology. Visual word recognition, that is, recognition of the printed word, requires two types of knowledge, or skill: decoding skill and word-specific lexical knowledge (Gough & Wren, 1998). In the context of decoding, Gough, Hoover and Peterson (1996) explained that in order to recognize a written word, the reader has to translate a meaningless set of letters into a recognizable object and locate or activate precisely the right word in the mental lexicon. Harris and Beech (1998) reported significant differences in the word recognition in deaf and hearing children, and phonological awareness appeared an important factor in both groups.

The objective of the present study was to investigate the effect of the use of CIs on the literacy of deaf children. As argued above, we define reading skills as reading comprehension and visual word recognition. We expected the auditory information provided by CIs to be sufficient to enhance the poor reading comprehension in deaf children, partly via improvement of visual word recognition skills. In the first part of the study we investigated to which extent a cochlear implant improved the *reading comprehension* in deaf children. Therefore, the reading comprehension in deaf children with at least 3 years of cochlear implant use was contrasted with that in deaf children without CIs and to that in children with normal hearing. In the second part of the study, we evaluated the *visual word recognition* in deaf children with and without CIs and in children with normal hearing. In the third part of the study we analysed the *relation* between visual word recognition and reading comprehension in children with and without CIs. Moreover, we investigated whether the expected positive effect of cochlear implantation on reading comprehension remained when the contribution of visual word recognition was controlled for.

2.2 Method

2.2.1 Participants

This study addressed the reading skills of three groups of children: deaf children with CIs (DCI group), deaf children without CIs (D group) and children with normal hearing (H groups). Subject characteristics of these three different groups of participants are described in detail in Par. 1.2.

2.2.2 Materials

Reading comprehension assessment

The 'Reading Comprehension Tests' (Begrijpend Leestests, Aarnoutse, 1996), standardized for the use in primary schools, were used to assess reading comprehension. Each single test, meant for a specific educational grade, consists of a booklet with 10 separate short paragraphs that have to be read silently, followed by 25 to 30 four-choice questions. The text remains available during answering and there is no time limit. The number of correct answers is the raw test score. Raw scores are converted into 'latent scores' that are applicable to all grades of primary and secondary education (Nijmegen Pupil Monitoring System; Aarnoutse, van Leeuwe, Oud, Voeten, Manders, Hoffs, & van Kan, 2000).

As a basis for comparing the reading comprehension scores of the deaf and hearing children we used instructional ages instead of chronological ages. Instructional age makes an adjustment for the amount of formal reading instruction a child received. This adjustment was necessary because in deaf children the amount of formal reading education cannot be derived directly from their school grade. Generally they do not commence with formal reading instruction at the same age as children with normal hearing. Furthermore, the curricula in special education differ from those in mainstream education. For example: a deaf child may enter elementary education (grade 1) at the age of 7, whereas a hearing child is 6 when entering school. After 4 years of education this deaf child may be in grade 3, while the hearing child will be in grade 4. When the deaf child is 11 years old child it might be in third grade, a level obtained by hearing children at the age of 9. The use of instructional age, the amount of formal reading instruction perceived, yields a grade 'equivalent' of 4 years for this deaf child, although the actual educational grade the deaf child is in, is grade 3. An instructional age was computed for each child in the DCI group in the same manner as that used on the D group,[5] in the study by Wauters et al. (2006). The instructional ages of the children of the DCI group were, on average, 13 months below their chronological ages. In what follows, for hearing children the notions: chronological age and grade will be used, for deaf children these are adjusted to: instructional age and grade-equivalent.

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5 The number of months of formal reading instruction in the D group was obtained by means of a parent questionnaire. In case of unreliable or missing data, they were estimated. The computations were based on all available data of the D group. The 'instructional age' in the D group was computed as follows: Instructional Age (IA) = -55.398 +0,811*age.

The broad instructional age range in the DCI group and hence, the limited number of participants per grade-equivalent complicated further analyses. Therefore, the scores were grouped by combining them into four '(equivalent) grade levels'. Grade level A: children in primary grades one to and including three; grade level B: children in primary grades four to and including six; grade level C: children and adolescents of secondary grades seven to and including nine; grade level D: adolescents in secondary grades ten or higher.

Visual word recognition assessment

Visual word recognition skills were assessed with the two lexical-decision tasks described in the study by Wauters et al. (2006). One lexical-decision task (the Silent-reading task) used a list of 160 monosyllabic letter strings (CVC, CV or VC), that were either highly frequently occurring words or orthographically legal pseudo-words (ratio of 1:3). The words were 30 nouns, 5 adjectives and 4 homonyms that could be a noun, an adjective or an adverb. The words were presented in columns at the test form. Respondents have to cross out, column wise, as many pseudo-words as possible in one minute. The number of items judged correctly within one minute is the raw score. The other lexical-decision task was the Two-choices task, that consisted of 80 word pairs, containing a word and a pseudo-word. Respondents have to cross out as many of the non-existing items of a word pair as possible in one minute. The words were 62 nouns, 3 adjectives, 1 verb and 14 homonyms that could be either a noun or an adjective. Children who tend to underestimate their word knowledge or are fast instead of accurate might accept pseudo-words. The second task excludes this possibility because for every pair they must mark one item as non-existing. The raw score was the number of times the word was identified correctly. In the analyses of visual word recognition the grade levels described above were also used.

2.2.3 Procedure

The reading comprehension tests and the visual word recognition tasks were administered to the DCI group similar to the method used to assess the children in the D group; teachers or peripatetic teachers administered the tests at school, where possible in groups, after receiving detailed written instructions about the assessment protocol. There were regular schools, schools for the hard-of-hearing and schools for the deaf involved in the assessment.

2.3 Results

To investigate whether the use of a cochlear implant improved the poor reading skills of deaf Dutch children, first, we describe the findings regarding reading comprehension and second, regarding visual word recognition. Next, we discuss the relation between visual word recognition and reading comprehension in deaf children with and without CIs.

2.3.1 Reading Comprehension

To evaluate the effect of CIs on the reading comprehension in deaf children the scores of the DCI group are compared to those of deaf children without CIs. Moreover, the scores the two deaf groups, children with and without CIs, are then compared to those of hearing children. In conclusion we put forward considerations regarding the comparability of the characteristics of the DCI group and the D group.

Reading comprehension of deaf children with and without CIs

Table 1 shows the mean reading comprehension scores for the DCI group and D group per grade level. Figure 1 shows the individual reading comprehension scores of children in the DCI group per grade-equivalent, with the mean scores for the D and the H group depicted as reference curves.

TABLE 1

Number of participants, mean reading comprehension scores and standard deviations in the DCI and the D group per grade level, two-tailed significance level of the difference between the distributions and the effect-size

Grade level	*N*		*M*		*SD*		Two-tailed *p*	Cohen's *d*
	DCI	D	DCI	D	DCI	D		
A	8	47	21.75	18.03	4.43	2.44	*p*=.037	1.33
B	16	109	23.12	20.17	3.95	4.30	*p*=.053	0.69
C	14	168	28.18	22.70	4.34	4.92	*p*=.002	1.11*
D	12	140	30.82	24.59	4.01	5.39	*p*=.002	1.16

* Levene's test of homogeneity of error variances was significant. In this case the *SD* of the control group was used in the computation. In all the other cases, square roots of the pooled error variances were used.

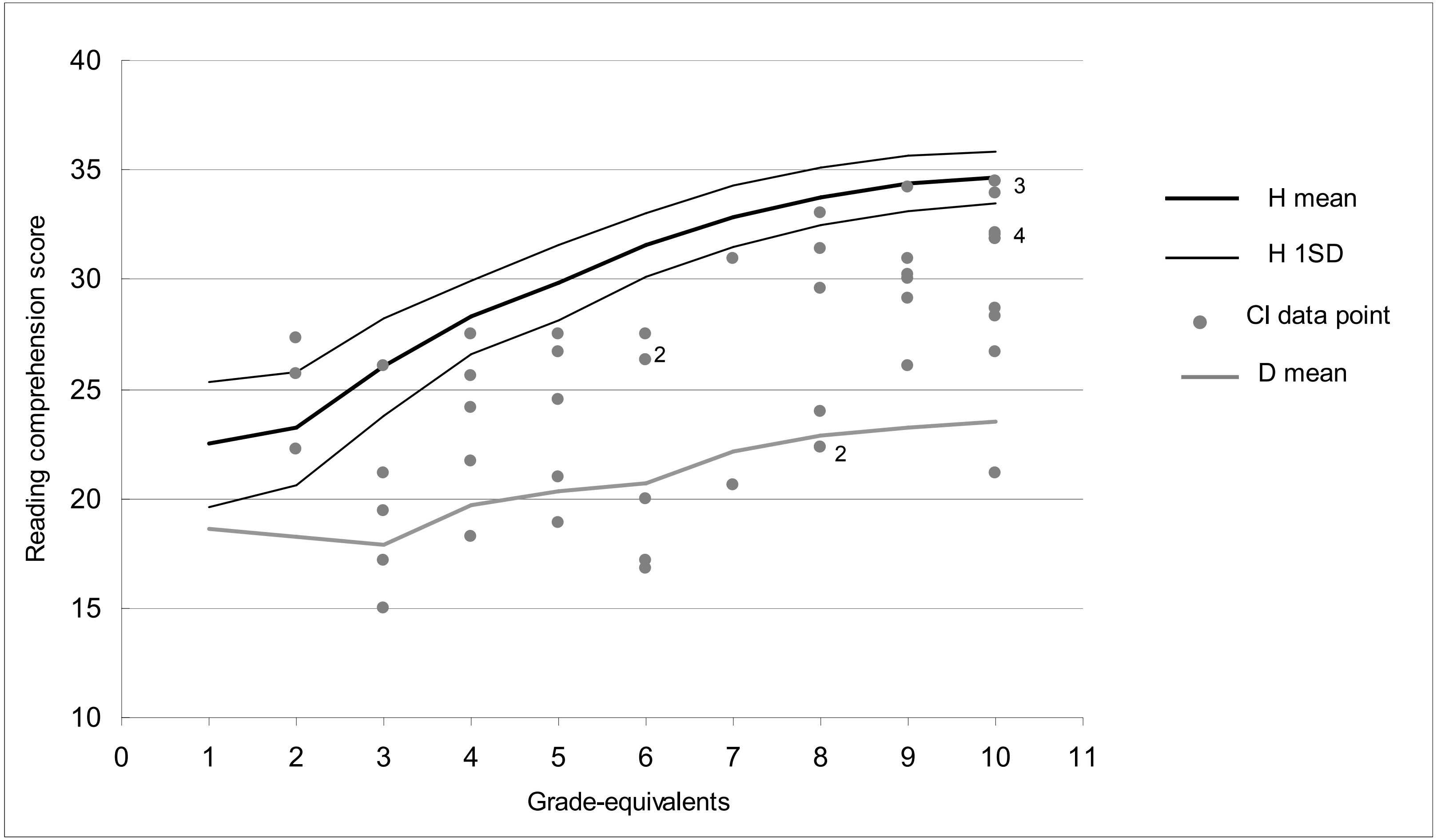


FIGURE 1 *Reading comprehension scores of the individual DCI participants (grey dots), mean reading comprehension score for the children with normal hearing (bold black line) 1 SD range (thin black lines) and the mean score for the D group (bold grey line), per grade (H) or grade-equivalent (DCI and D). Note that the SD for the D group was not included, because it was large and irregular*

The data of the H group are the norm data, as reported in the test manual (Aarnoutse, 1996). The DCI scores show a large variability and are mostly distributed between the mean scores for the H- and D group in all grade-equivalents. The mean scores for both the DCI group and D group- increased over the grade levels but at all grade levels the DCI group obtained higher mean scores than the D group. The Shapiro-Wilk test for normality showed that the reading comprehension scores in the D group did not have a normal distribution (*SW* statistic = .943, $df = 504$, $p = .000$). The reading comprehension scores of the DCI group had a normal distribution. For this reason the Kolmogorov-Smirnov Two Sample test (KS-test) was used to determine whether there were differences in the reading comprehension score distributions of the DCI group and D group. The non-parametric KS-test has the advantage of making no assumptions about the (normality of the) distribution of the data, since no parameters such as mean or median, are tested. This test concerns the agreement between the two cumulative frequency distributions that are compared. The difference between the two frequencies is determined for fixed score intervals. The KS-test focuses at the largest of these deviations (Siegel & Castellan, 1988). Significant differences were found between the distributions of the DCI group and D group at all grade levels, see Table 1. We also computed the effect-size of the difference between the group means, Cohen's *d* (Table 1). This parameter expresses the standardized difference between the means of two groups, $d = \mu_1\text{-}\mu_2 / sd(\varepsilon)$. The effect-size of the differences between the DCI group and the D group at grade levels A, C and D are large, whereas at grade level B it was medium. Cohen's d-values of .80, .50 and .20 were considered to be a large effect, a medium effect and a small effect, respectively (Van den Bercken & Voeten, 2002). Table 1 shows that the reading comprehension of the children with CIs was better than that of their deaf peers without CIs. Mostly the differences were large.

Reading comprehension of the deaf children with and without CIs compared to the hearing norm

After having found that the reading comprehension in the DCI group surpasses that in the D group, the reading comprehension skills of the two deaf groups were compared to the hearing standard. *z* scores were computed per grade, based on the means and standard deviations of the hearing norm group . Figure 2 shows the mean *z* scores. By definition the mean reading comprehension *z* scores of hearing children were equal to zero. The relative differences between the DCI group and the D group compared to the mean *z* scores for hearing children, are expressed in the number of ‘hearing' *SD*-units of deviation from the ‘hearing’ grade level mean *z* scores. The scores of the DCI group leveled off at between -3 and -4 *SD*. Relative performance in the D group however, decreased with increasing grade level, up to an *SD* of minus 8.6 at grade level D.

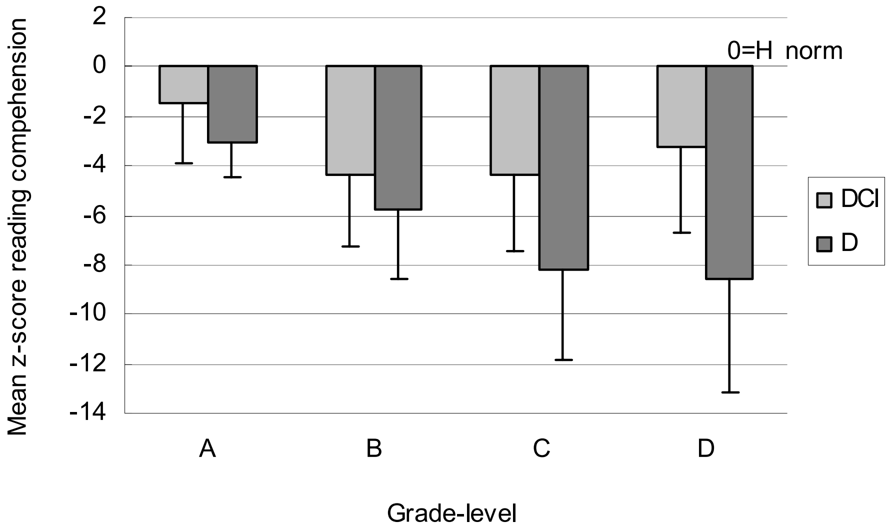


FIGURE 2 *Mean z scores and SD of reading comprehension for the DCI and the D group per grade level. By definition the H norm was z = 0*

Next the difference between the two groups of deaf children and the hearing norm was also quantified in another way. Table 2 shows the percentage of children in the DCI and the D group per grade level who performed ‘below’ or ‘in-or-above’ the 95% confidence interval of the children with normal hearing. The 95% confidence interval lies between -1.96 and 1.96 hearing *SD* (see figure 2) of the hearing mean *z* score (0), computed per grade level. Whether these percentages differ was determined with Chi-square tests. The percentage of children in the DCI group who performed in-or-above the 95% confidence interval of the children with normal hearing was significantly higher than that for the D group at all grade levels. These data showed that the performance of the deaf children with CIs deviated less significantly from the children with normal hearing than that of the deaf children without CIs.

TABLE 2

Percentages of children in the DCI and the D group who performed 'below' or 'in-or-above' the 95% confidence interval of the reading comprehension level of children with normal hearing, χ^2 values are shown of the differences between these percentages and one-tailed significance, per grade level

Grade level	percentage below , in-or-above 95% confidence interval of the H group				χ^2	*p*
	Below		In-or-above		*df* = 1	
	DCI	D	DCI	D		
A	50	83	50	17	24.44	*p*=.000
B	75	88	25	12	5.60	*p*=.009
C	71	93	29	7	16.50	*p*=.000
D	67	92	33	8	19.16	*p*=.000

Group characteristics of the deaf children in the DCI group and D group

As discussed in the introduction many factors are associated with reading comprehension in deaf children. Geers (2003) reported that performance intelligence quotient (PIQ), family socioeconomic status, gender, later onset of deafness, educational placement and ethnic background are important factors. In order to exclude the possibility that such child and environmental variables contributed to the difference in reading comprehension between the DCI group and D group, the comparability of the groups was examined. The influence of variables we could investigate, based on the available data, was gender, pre or post-lingual onset of deafness, (pre-implant) educational placement and ethnicity (Dutch or other nation of origin (no Dutch mother-tongue) of the parents). The PIQ's were not available for all the children in the DCI group and their effect could therefore not be investigated. However, Oakhill et al. (2003) found that PIQ did not have any effect on reading comprehension or on visual word recognition in children with normal hearing. As already mentioned in the Participants section, no children with learning disabilities have been included in the D and DCI group. Unfortunately data were lacking on the socio-economic status of the families of the children from either group. The data concerning the factors we could study were classified for the DCI group in the same way as those for the D group in Wauters' study. Onset of deafness was classified into *pre-lingual* (before the age of 36 months) or *post-lingual*. The factor pre-implant educational setting had the levels*: schools for the deaf*, *schools for the hard-of-hearing* and *mainstream education*. The factor nation of origin of the child's parents was either *Dutch*: two Dutch parents; *Dutch and other*: one Dutch parent and one parent of not-Dutch origin; *other*: both parents not Dutch. We carried out chi-square tests to determine the comparability between the DCI and D groups with respect to these factors. Table 3 shows these results.

TABLE 3

Percentages of children in the DCI and the D group per factor level. χ^2 value and one-tailed significance are included for the factors gender, national origin of the parents, onset of deafness and pre-implant educational setting

	%		χ^2	p
Factor and factor levels	DCI	D	$df = 1$	
	$N = 50$	$N = 504$		
Gender			0.180	p=.335
Male	50	53		
Female	50	47		
Onset of deafness			1.087	p=.150
Pre-lingual	90	94		
Post-lingual	10	6		
(pre-implant) educational setting			6.903	p=.032
school for the deaf	74	84		
school for the hard-of-hearing	22	9		
mainstream education	4	7		
Nation of origin of parents			8.860	p=.012
Dutch	92	79		
Dutch and other	6	20		
Other	2	1		

Gender can be considered to be equally distributed in the two groups. The same applied to the variable pre- or post-lingual onset of deafness. Significant differences were found in the percentages of participants classified according to parents' native origin and pre-implant educational setting. The DCI group contained more children with 'Dutch only' parents, the D group more 'Dutch and other'. In the DCI group more children were attending schools for the hard-of-hearing, while relatively fewer were attending schools for the deaf than in the D group. In the pre-implant situation in the D group more of the children had been receiving mainstream education than in the DCI group. Hence, analyses of variance were carried out to determine the effect on reading comprehension within the DCI group of the variables that differed between the DCI and D group; Parents' nation of origin and pre-implant educational setting. We included instructional age as the covariate because the correlation between age and reading comprehension, $r_s = .68$, $p < .01$, was strong. Pre-implant educational setting showed no significant effect on reading comprehension. The nation of origin of the parents however, showed a marginally significant effect ($F(2,46) = 3.36$, $p = .044$). From the outcomes of the chi-square tests we can conclude that gender and age at onset of deafness were not causing the differences in the reading comprehension of the DCI group and D group. The analyses of covariance (ANCOVA) showed that pre-implant educational setting did not affect reading comprehension outcomes. Based on the last ANCOVA, the only factor that could affect the reading comprehension difference between the DCI group and D group, apart from the use of a cochlear implant, was the nation of origin of the parents.

We considered it important to further analyse the data without the influence of the nation of origin of the parents. Although we found only a marginal significant effect of the nation of origin of the parents on reading comprehension in our sample, Wauters et al. (2006) reported that in the group of deaf children with conventional hearing aids, 20% of the poor readers were children with parents of another nation of origin compared to 5% of the better readers. Therefore, we re-analysed the reading comprehension scores of the two groups of deaf children, restricting the analyses to native Dutch children (children with parents of Dutch origin) only. The limited number of implanted children of other ethnic backgrounds, $n = 4$, in the DCI group did not permit further statistical analysis of their data. Table 4 shows the number of DCI and D group native Dutch children per grade level, the mean visual word recognition scores and standard deviations. The KS test showed significant differences between the DCI and D distributions at all grade levels. In order to express the effect-size of the standardized difference between the group means, Cohen's *d* values were computed for the native Dutch group. The KS *p*-levels and Cohen's *d* values are included in Table 4. The native Dutch children in the DCI group and the D group performed better on average, at every grade level, than the total groups (see also Table 1). The mean scores of the native Dutch children of the DCI group are higher than those of the D group and the distributions of the

DCI group and the D group, of native Dutch children, showed significant differences at all grade levels. Effects were large at all grade levels.

TABLE 4

Number of participants per grade level, the mean reading comprehension scores and SD for the native Dutch children in the DCI and the D group, two-tailed significance level of the difference between the distributions and the effect-size

	N		*M*		*SD*		Two-tailed *p*	Cohen's *d*
	Native Dutch		Native Dutch		Native Dutch			
Grade level	DCI	D	DCI	D	DCI	D		
A	7	37	22.40	18.11	4.35	2.68	*p*=.016	1.60
B	14	88	23.79	20.43	3.70	4.49	*p*=.031	0.75
C	13	131	28.35	23.28	4.47	4.96	*p*=.002	1.02
D	12	109	30.82	25.35	4.01	5.21	*p*=.002	1.05

Inspection of the latent scores revealed that four out of the five DCI children with the lowest scores per grade-equivalent were children of two not-Dutch parents. The performance of these non-native Dutch children at higher grade-equivalents was better than that of non-native Dutch children at the lower grade-equivalents, though.

Conclusions regarding reading comprehension

In conclusion, we found that at all grade levels the deaf children with CIs obtained slightly higher mean reading comprehension scores than the deaf children without CIs. There were significant differences in favour of the cochlear implant group, between the score distributions of the two groups of deaf children. The effect-size was substantial. These findings were not due to group differences of the variables gender or pre- or post-lingual onset of deafness. Furthermore, we have shown that pre-implant educational setting did not have any significant effect on reading comprehension within the group of children with CIs. Although there was a marginal effect of the nation of origin of the parents within the children with CIs, a comparison of the reading comprehension scores of the native Dutch children showed that the performance of the CI users was better than that of the children without CIs at all grade levels. Whether the use of another language than Dutch in the home environment was the only cause of this effect cannot be concluded from our data. Other factors that are known to negatively influence reading cannot be excluded from being present in these children's environments. Such factors are for instance a lower educational level of the parents and the limited use of sign language at home. No structural differences between the school environments of these and other children are known however.

Unfortunately, the positive effect of cochlear implantation did not prevent the reading comprehension of the children with CIs from lagging far behind that of the children with normal hearing. On average the performance of the children with CIs was still more than 3 standard deviations below the hearing norm, while for the children without implants the average was even as low as minus 7 standard deviations.

2.3.2 Visual Word Recognition

The second part of our study assessed the visual word recognition skills in deaf children with CIs, using the two lexical-decision tasks described in the Method section. The visual word recognition in deaf children with CIs is described and their skills are contrasted with those in deaf children without CIs and those in children with normal hearing. Furthermore the relative performance of the two groups of deaf children compared to the hearing norm was evaluated.

In order to derive a more robust variable we pooled the data from the two lexical decision tasks. The strong Spearman rank correlations (r_s) between the z scores on these two tasks, in the DCI group ($r_s = .80$, $p = .000$) and the D group ($r_s = .72$, $p = .000$), justified this. In our analyses we therefore used the mean of the z scores from task A and task B, further referred to as visual word recognition.

Visual word recognition of children with and without CIs and hearing children

For the purpose of investigating differences in visual word recognition skills between deaf children with and without CIs, and children with normal hearing we carried out pairwise Kolmogorov-Smirnov Two Sample tests (The scores of the children in the D group did not follow a normal distribution (*SW* statistic = .977, $df = 504$, $p = .000$), those of the DCI group did). But first the descriptives of visual word recognition in the three groups of participants are summarized in Table 5. The mean scores for the DCI group were higher than those for the D group, at all grade levels. In the two deaf groups an increase over grade levels was observed however, as in the hearing group.

TABLE 5

Number of participants, mean visual word recognition scores and SD for the DCI, D and H group per grade level

Grade level	*N*			*M*			*SD*		
	DCI	D	H	DCI	D	H	DCI	D	H
A	8	68	527	38.94	25.80	23.38	20.10	10.89	13.92
B	16	114	554	40.94	36.46	49.20	13.26	15.27	13.79
C	14	175	277	61.00	47.10	59.65	13.76	16.56	17.80
D	12	147	71	72.17	56.81	67.26	22.96	19.77	18.35

Table 6 shows the p-levels of the differences between the distributions of scores of the three pairwise combinations of groups per grade level. The effect sizes, Cohen's *d* values, were computed and are also included.

TABLE 6

Two-tailed significance level of differences between the distributions of the visual word recognition scores for the DCI, D and H group and the effect-size per grade level

	DCI versus D		DCI versus H		D versus H	
Grade level	KS	Cohen's *d*	KS	Cohen's *d*	KS	Cohen's *d*
A	*p*=.192	1.21	.151	1.11	.017	-0.17
B	*p*=.324	0.30	.063	-0.60	.000	0.91
C	*p*=.017	0.85	.562	0.08	.000	0.72
D	*p*=.040	0.77	.725	0.26	.003	0.54

No significant differences were found in the distributions of the visual word recognition scores between the DCI group and D group at primary education levels (grade levels A and B). At the secondary level (grade levels C and D), the visual word recognition skills of the DCI group were better than those of the D group. There were no significant differences in the distribution of scores between the DCI and the H group. In the D group, however, there were differences in favour of the H group at grade levels B, C and D. At grade level A the D group performed better than the H group. In the cases where the differences between the pairwise comparisons of visual word recognition score distributions were significant, the effect sizes of differences between means were medium: DCI versus D group at grade levels C and D, D versus H group at grade levels B, C and D and in one case the effect size was small: D versus H group at grade level A, in favour of the D group.

Similar to the reading comprehension results, the visual word recognition in the two deaf groups, relative to that of a reference group of hearing children was expressed in two more commonly used and comprehensible measures that are parametric, however. The raw scores on lexical decision tasks A and B were transformed into *z* scores, based on the hearing grade level mean scores and standard deviations. (The Hearing group is not the same group as the normative group of hearing children for the reading comprehension scores.)

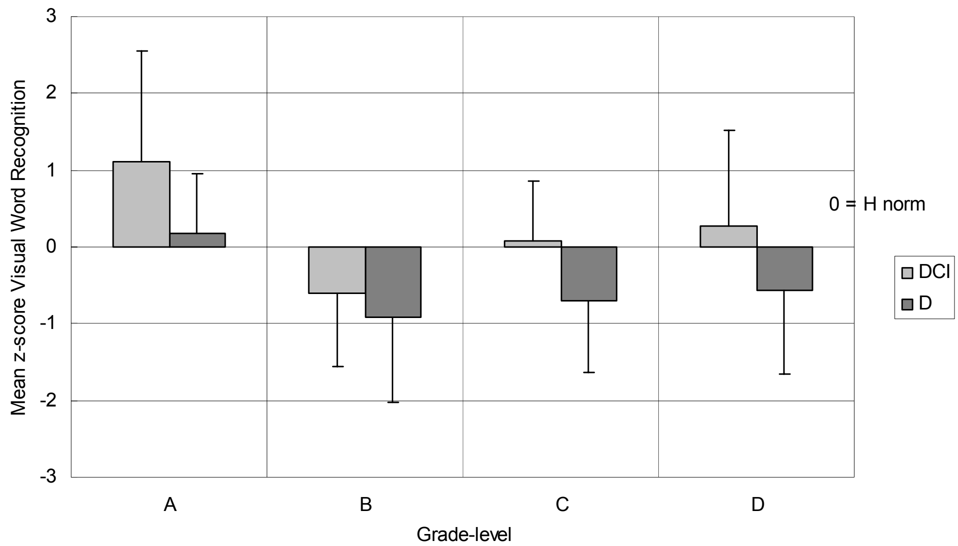


FIGURE 3 *Mean visual word recognition z scores and SD for the DCI and D group per grade level. The H mean by definition is z = 0, calculated per grade level*

Figure 3 shows the *z* scores of visual word recognition for the DCI group and the D group, relative to the 'hearing' mean, expressed in 'hearing' *SD* units. By definition the mean *z* scores for hearing children were equal to zero. The mean for the DCI group was .07, that for the D group was -.60. As with the raw scores, children in grade levels A and D in the DCI group obtained higher mean *z* scores than the H group mean scores, although the range is very large. For the D group the mean scores were lower those for the H group.

Table 7 shows the percentages of children performing below' or 'in-or-above' the 95% confidence interval of the children with normal hearing. These data showed that the DCI group had significantly better results than the D group at all grade levels except for level A, in which there was no difference between the two deaf groups. In this case the performances of both the DCI and the D group were better than that of the H group.

TABLE 7

Percentags of children in the DCI group and D group who performed 'below' or 'in-or-above' the 95% confidence interval of the visual word recognition level of children with normal hearing, χ^2 *values are shown of the differences between these percentages and one-tailed significance, per grade level*

	percentage below , in-or-above 95% confidence interval of the H group				χ^2	*p*
	Below		In-or-above		(*df* = 1)	
Grade level	DCI	D	DCI	D		
A	0	0	100	100	-	-
B	0	22	100	78	24.72	*p*=.000
C	0	10	100	90	10.53	*p*=.001
D	0	7	100	93	7.25	*p*=.007

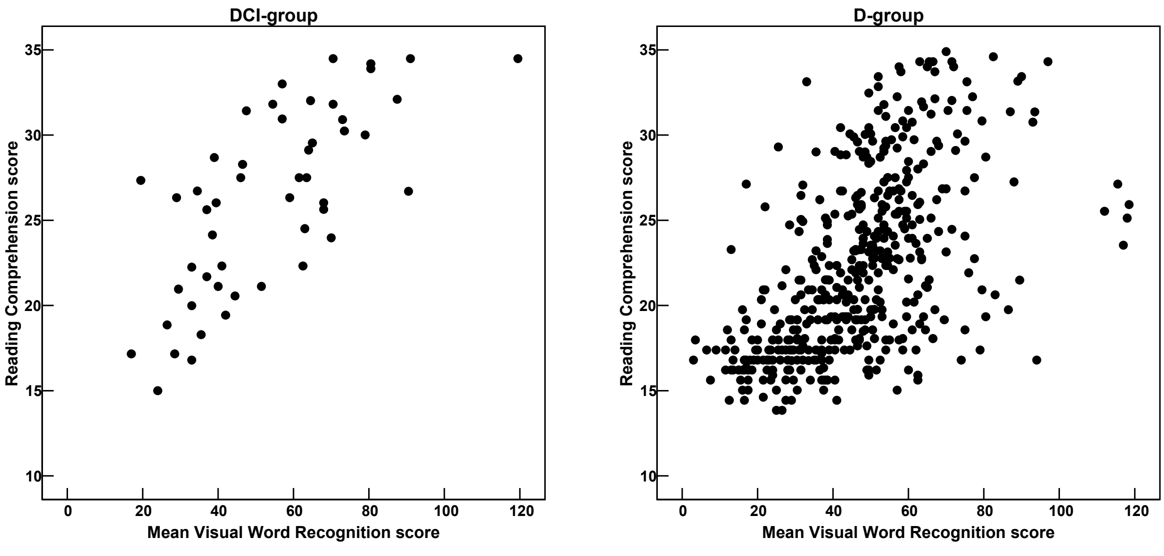
Conclusions regarding visual word recognition

An important finding was that, although the visual word recognition skills of deaf children without CIs were below that of hearing children, after the same amount of reading instruction, the visual word recognition skills of the children with CIs did not differ significantly from those of the hearing children. Furthermore, at secondary education level the visual word recognition skills of deaf children with CIs were better than those of children without CIs. No differences between children with and without implants, however, were found at primary level. From the *z* scores we can conclude that in comparison with the visual word recognition skills of the children with normal hearing, the abilities of the two groups of deaf children were relatively good, that is, mostly within 2 *SD* of the hearing grade level mean.

2.3.3 The relation between visual word recognition and reading comprehension

In this section we examine the relation between visual word recognition and reading comprehension in deaf children with and without CIs. First, we studied the association between these two skills in the DCI group and the D group. Moreover, we evaluated whether the reading comprehension in deaf children with CIs remained better than that in children without CIs when the influence of visual word recognition was controlled. As shown above, the reading comprehension in deaf children with CIs was significantly better than that in deaf children without CIs, while no significant differences were found in their visual word recognition in elementary education, but only in secondary education. Therefore, we analysed the contribution of visual word recognition skills to the reading comprehension in the DCI and D group at the four grade levels.

Spearman rank correlations were calculated between the visual word recognition scores and the reading comprehension scores. This value was $r_s = .73$, $p < .01$ in the DCI group and $r_s = .61$, $p < .01$ in the D group. Figures 4 a and b show the scatter plots of the visual word recognition and the reading comprehension scores. The distributions of the scores of visual word recgonition and of reading comprehension of the deaf children without and with CIs are fairly similar, suggesting that the visual word recognition might not be responsible for the difference in reading comprehension between the two groups of children.



FIGURES 4 A & B *Scatter diagrams of the visual word recognition scores (x-axis) and the reading comprehension scores (y-axis) for the DCI and the D group, respectively*

Further examination of the data aimed to determine the explanatory power of visual word recognition on reading comprehension. Separate linear regression analyses were carried out on the DCI and the D group. In the DCI group visual word recognition explained 52% of the variance of reading comprehension, while in the D group only 32% of reading comprehension variance was explained by visual word recognition. We found large differences in the results of the D group between primary education (34% explained variance) and secondary education, (only 21%). We found that in the DCI group visual word recognition accounted for 13% of the variance in reading comprehension, after the variance due to instructional age was removed (Beta = .49, $t = 3.85$, $p = .000$).

An ANCOVA was carried out to evaluate the effect of the factors group (with two factor levels: *cochlear implant* versus *no cochlear implant*) and grade level on reading comprehension, with visual word recognition as the covariate. No interaction of the factors group ('CI' versus 'no CI') and grade level with the covariate visual word recognition were found, which implies parallel slopes and homogeneous regression and justifies straight-forward analyses of covariance. Eliminating the effect of visual word recognition, we found significant effects of group ($F(1,513) = 26.63$, $p < .001$) and grade level ($F(3,513) = 4.67$, $p < .005$) on reading comprehension. There was an effect of group on reading comprehension that applied to all grade levels. The effect of group was still present after the contribution of visual word recognition skills on reading comprehension had been ruled out. This suggests that the difference in reading comprehension between the deaf children with and without CIs was not explained by differences in word recognition skills alone.

Table 8 shows that the differences in reading comprehension between the two deaf groups at each grade level are still present when the reading comprehension scores were adjusted for the effect of visual word recognition.

TABLE 8

Mean adjusted reading comprehension scores for the DCI and D group, per grade level

Grade level	*M*	
	DCI	D
A	23.39	20.60
B	22.89	21.47
C	26.46	22.62
D	27.47	23.10

The predicted means for reading comprehension, after eliminating the influence of visual word recognition are depicted. Comparison with the results summarized in Table 1, shows that the differences between the scores of children with and without implants were of a similar magnitude after adjusting for the effect of visual word recognition.

We demonstrated that there was high correlation between visual word recognition and reading comprehension in the two groups of deaf children, but that the contrasts between visual word recognition skills of the deaf children with and without CIs did not explain the differences in reading comprehension. This is in accordance with the Simple View of Reading model (Hoover & Gough, 1990), because language competence is a second factor that on its own or in combination with visual word recognition might explain variance in reading comprehension.

2.4 Discussion

The objective of our study was to investigate whether the use of a cochlear implant was associated with improvements in the poor reading skills of deaf Dutch children. To evaluate this, the reading comprehension in children who had been using their cochlear implant for at least 3 years was compared to that in deaf children without CIs. In addition the scores obtained from these two deaf groups were evaluated in relation to those of two groups of children with normal hearing. To gain further insight into the causes of differences in reading comprehension between the deaf children with CIs and those without, we investigated the relation between visual word recognition and reading comprehension.

In the Introduction, we mentioned that reading comprehension in deaf children without CIs seemed to be lagging behind that of hearing children (Holt, 1993; Holt et al., 1996; Traxler, 2000). A recent large scale study by Wauters et al. (2006) showed that deaf children without CIs in the Netherlands also had very low reading comprehension levels compared to children with normal hearing. As expected, we found that the reading comprehension performance of deaf children with at least 3 years of cochlear implant use was better than that of deaf children without CIs. Our results show that the use of a cochlear implant was associated with improvement of the reading skills of deaf children. Within the available data, there were no secondary group characteristics that could account for the differences between the scores of the deaf children with and without CIs. Nevertheless, the reading comprehension of deaf children with CIs was still lagging behind that of the children with normal hearing. As a group, the average performance for the deaf children with CIs was - 3.6 *SD* below the norm, but it was much better than the mean for the deaf children without CIs (-7.2 *SD*). Over the four grade levels, the percentage of children with CIs whose performance was within or above the 95% confidence interval of the children with normal hearing varied between 25% and 50%. At each grade level this percentage was significantly higher than that of the deaf children without CIs.

Until now only a few studies have assessed reading comprehension in deaf children with CIs. In agreement with these studies, we found that the reading comprehension skills of the children with CIs were better than those of the deaf children without implants, but were poorer than those of the children with normal hearing. The reading comprehension level of the children with CIs in our study was slightly lower than the levels reported in the studies by Geers (2003) and by Spencer et al. (2003). About half of their children with CIs performed within the 1 *SD* range of the norms of hearing children. In our sample, half of the youngest children performed within 1.96 *SD* of the hearing mean, whereas at the three highest grade levels this applied to only about 25% of the children. The differences between our findings and those reported by Spencer and by Geers may have been caused by subject and environmental characteristics or by the tasks used to measure reading comprehension. Group characteristics that deviated included the speech coding strategies of the speech processors. Some of the children who participated in our study were using M-PEAK speech processors. Recent coding strategies, such as SPEAK and ACE, with wide dynamic ranges, are known to provide auditory input with speech characteristics that facilitate the use of phonological coding. Furthermore, our participants had a relatively long duration of deafness and an older age at implantation, which is known to limit auditory speech perception after cochlear implantation. Thus, if the positive effects of CI on literacy take place via enhanced auditory perception, possible explanations for differences between the findings reported in the recent literature on literacy in children with CIs and the results of our study are the indication criteria for implantation applied by the implant centre and the available coding strategies.

In an attempt to explain the better reading comprehension of the deaf children with CIs we investigated the relation between visual word recognition and reading comprehension. According to the Simple View of Reading model devised by Hoover and Gough (1990), reading comprehension is the product of word recognition and language comprehension, and visual word recognition explains a large part of the variance in reading comprehension. Lower visual word recognition skill levels were reported by Harris and Beech (1998). In other studies, no significant differences were reported between deaf children without CIs and children with normal hearing (Burden & Campbell, 1994; Fischler, 1985). However, the latter studies were performed on older children. The visual word recognition skills of deaf Dutch children without CIs were only slightly poorer than those of children with normal hearing (Wauters et al., 2006). In the present study we found that the visual word recognition skills of the children with CIs were better than those of children without CIs only at secondary education level, not at primary education level. Our data might reflect a similar trend to that described by Burden and Campbell (1984) who did not find any differences in visual word recognition skills between relatively old deaf children without CIs and their peers with normal hearing, and by Fischler (1985).

When Merrills et al. (1994) investigated the contribution of visual word recognition to reading comprehension; they found that poor visual word recognition skills only explained part of the reading difficulties in deaf children without CIs. Marschark and Harris (1996) argued that, apart from phonological recoding, vocabulary and syntax were expected to account for reading difficulties. Indeed, Wauters et al. (2006) reported similar results in deaf Dutch children without CIs. They stated that even if the visual word recognition scores of the children without CIs would have been age-appropriate, their reading comprehension would have still lagged behind that of children with normal hearing. We found that although the reading comprehension in deaf children with CIs was poorer than that in children with normal hearing, there were no large differences in visual word recognition. Nevertheless, these two skills were correlated in the children with CIs (note that the reference data for reading comprehension and visual word recognition were from two different groups of hearing children), which is also the case in the hearing population. Differences in visual word recognition between the children with CIs and the deaf children without CIs could not explain the contrast in reading comprehension skills between these two groups. The better reading skills of the children with CIs can be attributed to their implants and must depend on other factors than visual word recognition alone.

In the Simple View of Reading model (Hoover & Gough, 1990), reading comprehension is defined as the product of single word reading and listening skill (language competence). Part of the difference in reading comprehension between the deaf children with and those without CIs should therefore lie in language comprehension according to the model.

Wauters et al. (2006) argued that he reading comprehension problems of deaf children without CIs might also be the result of linguistic-comprehension factors. We argue that it is highly plausible that language skills make a prominent contribution to the better reading comprehension of children with CIs. Indeed, frequent reports have been published on enhanced language skills after cochlear implantation and many authors described increases in the development of vocabulary after cochlear implantation, (e.g. Connor et al., 2006; Svirsky et al., 2002; Tomblin, Spencer, Flock, Tyler & Gantz, 1999; Vermeulen et al., 1999). Fewer data are available on the development of morpho-syntactic skills. Spencer et al. (1998) reported that CI users demonstrated better perception and comprehension of bound morphemes than hearing aid users. Svirsky et al. (2002) and Szagun (2004) compared the morphological development of children with CIs to that of children with normal hearing and found different patterns. However, in the latter studies, the tasks involved speech production. Nevertheless, all the studies indicate that auditory perceptibility strongly influenced the development of morphological skills in children with CIs. Markers (morphemes) that are best perceived through audition are the first to be produced. Another language component that is associated with reading comprehension is narrative skill. Several studies reported improvements in narrative abilities after implantation (Nikolopoulos, Dyar, Archbold, & O'Donoghue, 2004). Furthermore Crosson and Geers (2001) not only found that narrative skills improved after cochlear implantation, but also that they had predictive value for reading comprehension in children with CIs.

In conclusion, cochlear implantation was positively associated with reading comprehension of deaf children. This is a very important finding; improved reading comprehension may increase their academic achievements and promote their participation in society. In our opinion, the achievement of auditory access to spoken language caused the swift progress in reading comprehension. Although the visual word recognition skills of the children with CIs were better than those of the deaf children without CIs, this does not explain the superior reading comprehension skills of the cochlear implant users. The results of this study did not provide a clear answer to the question of *how* (i.e. through which specific aspects of language competence) the improvements in reading comprehension were actually brought about.

Chapter 3 ● **Speech perception and language development and their contributions to reading skills**

We showed that reading comprehension in profoundly deaf children with cochlear implants was better than in deaf children without CIs (Paragraph 2.3.1). Moreover, we found that visual word recognition skills in deaf children with CIs surpassed that in deaf children without CIs in secondary education (Par. 2.3.2). When we controlled for the contribution of visual word recognition skills to reading comprehension, the difference in reading comprehension scores between deaf children with and without CIs remained significant (Par. 2.3.3). We argued that it was likely that improved language skills also positively influenced the reading comprehension performance of deaf children with CIs. We also stated that in our opinion the better auditory access to spoken language after cochlear implantation facilitated this higher level of reading comprehension of deaf children. For, as described in the Simple View of Reading Model of Hoover and Gough (1990), decoding and language components both are necessary for comprehension of written text. However, the analyses in Chapter 2, of the reading comprehension and the visual word recognition skills (decoding skill), permitted no conclusion yet about the way in which auditory speech perception influenced those skills.

In the present chapter we study the post-implant development of auditory speech perception skills and language components. Moreover, we explore the relation between post-implant auditory speech perception, language skills and reading skills. The reading skills that we evaluate are reading comprehension and visual word recognition. The influence of audiological and environmental variables on reading skills, auditory speech perception and language skills is also investigated. In what follows in this Introduction section we discuss how we address these issues and we describe which variables we study and what our expectations are.

3.1 Introduction

With respect to the development of auditory speech perception after cochlear implantation many positive results have been reported in literature (Par. 1.1). In profoundly deaf children access to the full range of speech sounds cannot be provided by the use of conventional hearing aids. Progressive increase of the results of speech perception has been reported in literature. Osberger (1991) found children with 22 Nucleus devices to perform at levels comparable with hearing aid users with a hearing loss above 100 dB. Boothroyd, Geers and Moog (1991) reported similar results. In the large scale Sensory Aids Study by Geers and Moog (1994) advantages are reported of cochlear implant users compared to hearing aids and vibro-tactile aids users for the perception of specific speech features. Studies regarding the perception of phonological speech contrasts with CIs showed performances comparable to those of children with hearing aids that have hearing losses of 88 dB (Boothroyd & Eran, 1994). A level of 78 dB was reported by Blamey, Sarant, Paatsch, Barry, Bow et al. (2001). However, Snik, Vermeulen, Brokx, et al. (1997) reported levels of equivalent hearing loss of 70 dB in post-meningitic deaf children after 36 months of implant use, outcomes in congenitally deaf children were less. Many studies reported that a better speech perception in children was associated with a lower age at implantation (Meyer et al., 1998; Svirsky et al., 2004). The development of auditory speech perception skills after implantation for the DCI group (Par. 1.2) is studied in this chapter.

Higher degrees of hearing loss were found to be associated with limited reading comprehension performances in profoundly deaf children (Conrad, 1979; Marschark & Harris 1996). Geers & Moog (1989) found that the factor degree of hearing loss also was a determinant of reading comprehension, that is, children with more residual hearing tended to have better reading comprehension. This is in agreement with the results reported by Wauters et al. (2006). The latter findings concern children without CIs however. No results regarding an association between reading and auditory speech perception performance after implantation have been reported yet. Nevertheless, Boothroyd & Boothroyd (2002) found that the better reading performance of children with CIs may be associated with better speech perception skills. But better speech perception skills after cochlear implantation have not been found to be independently predictive of reading levels. Instead, Geers (2003) found that overall language competence was most strongly associated with reading outcomes. The latter finding is in accordance with the Simple View of Reading model (Hoover & Gough, 1990), which states that language comprehension is one major component that is contributing to reading comprehension. Language knowledge that is important in reading in deaf children is thought to involve semantics and syntax (Musselman, 2000; Marschark & Harris, 1996). Many studies showed that semantic knowledge of deaf children was very limited (Knoors, 2001; Paul, 2003). Several studies showed that vocabulary increased after implantation (Miyamoto, 2003; Robbins, 2004; Svirsky et al., 2002, 2004). After implantation the rate of vocabulary development was faster than before implantation, and faster than that in deaf children without CIs. We studied the development of receptive vocabulary of the DCI group in this chapter.

Furthermore, post implant developments of the language component morpho-syntactic competence are reported in literature. Important morphemes are not always perceived via audition in deaf persons who use hearing aids. Some of the most important morphological markers are high-frequency sounds or are unstressed in speech. Cochlear implants, however, make such information accessible. Spencer et al. (1998) reported facilitation of the perception and comprehension of bound morphemes in CI users in comparison to hearing aid users. Szagun (2004) and Svirsky et al. (2002) reported different morphological development patterns in children with CIs when compared to the morphological development of hearing children. In the latter studies, however, the tasks that were administered involved speech production of the participants and poor speech intelligibility can influence interpretation of the results. All studies, however, indicated that auditory perceptibility strongly affects the development of morphological skills of children with CIs. The markers that are best perceived through audition were the first to occur in production. The morpho-syntactic competence of the DCI group was also studied in this chapter.

Another important contributor to reading is phonological skill. Phonological skill plays an important role the decoding of written text. Decoding is the process of translating print into a mental representation (code) for further processing. The internal representation can be orthographically or phonologically based. Most hearing persons seem to use phonological processing when they are reading. They convert printed text into a phonological representation, based on grapheme to phoneme correspondences (sound-out) and phonological skill. Phonological representation is the most efficient manner to keep the words in short term memory, while reading an entire sentence. The majority of profoundly deaf children with conventional hearing aids, on the contrary, do not have access to phonology via audition, although via other modalities some phonological information can be acquired

(Hanson & Fowler, 1987; Marschark, 2002). In literature divergent results have been reported but mostly profoundly deaf children without CIs showed limited or no auditory access to the phonological representation of words. Differences are difficult to interpret, however, because the degree of hearing loss of the studied samples was not always clear, different tasks were used, and the ages of the studied samples varied substantially. However, generally, studies have reported the use of phonologically based decoding in hearing impaired children with relatively good auditory perception skills (Leybaert, 1993; Geers, 2003). Hanson and Fowler (1987) used a lexical decision task and found that deaf college students with good reading skills showed access to phonological information. They reported that the use of phonological codes was related to better speech intelligibility. Nevertheless, most deaf children show slow and inaccurate decoding skill (Knoors, 2001). But, as discussed in Par. 2.1, in deaf subjects access to phonology is associated with better reading skills (Conrad, 1979; Hanson & Fowler 1987; Leybaert, 1993). Therefore, it is likely that access to auditory information as provided by CIs will enhance phonological skill in deaf children. Thus, we expect that phonological text decoding skill facilitates visual word recognition and reading comprehension in deaf implant users. To test this, we assess the phonological text decoding skill of children with CIs and investigate the association of the quality of their reading skills with the use of phonological codes during word reading.

The reading competence of children with CIs is also associated with audiological and environmental variables (Geers, 2003), apart from the relation with language components.

These audiological variables include age at onset of deafness and duration of deafness until implantation. Although CIs provide electrical stimuli directly to the acoustical nerve endings, the limited frequency and temporal resolution of the damaged cochlea and higher neural structures of deaf persons often are not capable to process this information optimally. It is important to differentiate between the threshold of hearing and the auditory speech perception. The threshold of hearing is the sensitivity level at which an auditory stimulus can be detected. Speech perception refers to the ability to recognize (elements of) spoken words. The variability of the threshold of hearing in children with implants is small while the speech recognition skills can differ tremendously. In principle the auditory input of a cochlear implant recipient can be programmed (tuned) in such a manner that it contains all essential speech features. Nevertheless, the age at onset of deafness and the duration of deafness do affect the processing capacities of the nervous system. The earlier the onset of deafness and the longer the duration of deafness, the larger is the detrimental effect on the auditory system.

As a consequence these factors cause difficulties in the perception of speech and, therefore, in the acquisition of spoken language. In addition, the presence of residual hearing reduces the effect of deprivation of the auditory system. The more residual hearing a deaf person has, the less the effect of the duration of deprivation is. Therefore, the pre-implant degree of hearing loss is another variable that influences speech perception, language skills and reading performance of deaf children with CIs. Pre-implant residual hearing can facilitate post-implant speech perception. In this chapter we assess the influence of these audiological factors on reading skills (Zwolan, Zimmerman-Phillips, Ashbaugh, Hieber, Kileny & Telian, 1997; Tyler et al. 1997) the auditory speech perception and language development with a CI.

Several variables from the environment in which the child is brought up and educated were reported to be associated with post-implant performances (regarding speech perception, language and reading). One of these factors is educational placement, which in some studies was classified at the levels placement in special versus mainstream settings while in other studies the levels were a quantification of the use of spoken language versus sign language. In most studies children oral/aural settings showed most progress. Geers, Brenner et al. (2003) found educational factors to account for 12% of the variance (after variance due to child and family characteristics was removed) of the speech perception skills. The only educational factor that made a significant independent contribution to speech perception, was the communication mode used in the classroom. Geers (2006), however, also argues that children with better speech perception skills are the ones that tend to be placed in mainstream settings. The use of (sign supported) spoken language was associated with better speech perception and with language outcomes (e.g. Geers, Nicholas et al., 2003; Miyamoto et al., 1999; Svirsky et al., 2000) Higher levels of literacy acquisition for deaf children educated with an oral–aural approach were also reported (Geers & Moog, 1989). In orally educated profoundly deaf adolescents, better reading achievement was found to be associated with better use of residual hearing and better levels of spoken English. An auditory-verbal emphasis is therefore expected to contribute more to the language and reading performance of CI recipients than to that of conventional hearing aid users. We study the effect of two environmental variables, educational setting and the emphasis that is placed on an auditory approach, on post-implant reading skills, auditory speech perception and language development.

In conclusion, we expect that the auditory speech perception and language develop better after cochlear implantation and therefore we study these developments during the first three years after cochlear implantation. Furthermore we expect that better language skills are associated with better auditory speech perception skills. We hypothesize that a higher level of reading skills in children with CIs is associated with better auditory speech perception and with better language skills.

In this chapter we commence in Par. 3.2 with a description of the direct relation between audiological and environmental variables and reading skills. In Par. 3.3 we study the development of auditory speech perception after implantation and we explore its relation with reading comprehension and visual word recognition. Par. 3.4 deals with the language development after implantation and the relation between language skills and reading skills. In Par. 3.5 we explore the influence of auditory speech perception on receptive vocabulary. The results are discussed in Par. 3.6.

In the analyses that are presented in this chapter we study several age or instructional age related variables, such as language skills, reading comprehension or visual word recognition. In those cases we want to control for this factor. For that reason in the analyses of variance that we report, the variable instructional age is included as a covariate. In all regression analyses with language, reading comprehension or visual word recognition as criterion variables, the variable instructional age is entered separate in a first stage, to control for the effect.

3.2 Audiological and environmental variables

We investigated the effect of audiological and environmental variables on reading skills. The most important audiological characteristics that influence auditory perception skills are the variables age at onset of deafness and duration of deafness until implantation. In Par. 3.2.1 the effects of these two factors on reading comprehension and visual word recognition are studied. We also assess the auditory threshold that was obtained with cochlear implant, and we compare it to the thresholds with and without hearing aids. Furthermore we investigate the relation between the hearing threshold with a cochlear implant and the audiological characteristics. Relevant environmental variables that we included in our study are the educational setting a child is in and the emphasis that is placed on the auditory approach, at home and in the school environment. The relation between these variables and reading are investigated in Par. 3.2.2.

3.2.1 Audiological variables

In our analyses we included two audiological characteristics, related to the etiology of deafness and the age at implantation. First, the relations between the factors ‘age at onset of deafness’ and ‘duration from onset of deafness to implantation’ and reading skills were studied. In the first part of this paragraph we introduced a variable that expressed the combined effect of both variables. First the relation between the post-implant threshold of hearing and reading skills was assessed.

Auditory sound detection levels

We determined the threshold of hearing with CIs in our group of participants in order to verify if the CIs were functioning accurately and were improving the sound detection levels for each audiological profile level to a similar extent. For each child in our group audiometrical data in three different aid-conditions were available. Earlier, the pre-implant auditory detection threshold without hearing aid had been determined and also the pre-implant threshold with conventional hearing aids. These two pre-implant audiometrical measures were part of the standard clinical selection procedure. In addition we assessed the threshold with a cochlear implant. This post-implant threshold was measured after the fitting procedure with CIs was completed (at least after 6 weeks post implantation). The detection level of auditory stimuli was measured with standard audiometrical procedures by an audiologist/audiological assistant. In an auditory test-room, free field pure tone stimuli were given at 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. Pure Tone Averages (Par. 1.2) of the frequencies 500, 1000 and 2000 Hz were calculated. Table 1 shows the mean PTA’s, in dB HL, in the three aid-conditions. As can be seen, the children on average have a profound hearing loss, that is, 119 dB without hearing aids. There is only a small variability, due to the maximum amplification that can be used for the measure, which in most cases was 120 to 125 dB. With the use of conventional hearing aids, hearing thresholds are still above the intensity of speech (60 dB). With CIs the threshold is below that level, on average 50 dB, which means that speech sounds can be perceived. With CIs there was also a small variability because the threshold is, in the fitting procedure by the audiologist, deliberately put on a fixed level.

TABLE 1

Mean hearing thresholds and SD, in unaided condition, with conventional aids and with CI

Detection thresholds PTA (dB HL)	*M*	*SD*
Unaided	119.46	5.54
Aided with conventional hearing aids	86.50	8.38
Aided with CIs	49.50	4.30

Paired sample t-tests showed, as expected, that the aided threshold with CIs was better than both, aided and unaided, thresholds before implantation. The threshold with hearing aids was better than the unaided one ($t(49) = 14.88$), p =.000). The threshold with implants was better than that with conventional hearing aids ($t(49) = 11.47$, p = .000) and, of course, than under the unaided condition ($t(49) = 80.25$, p = .000).

After finding that hearing levels with CIs were better than those with conventional hearing aids, we investigated the association of reading skills with the PTA in the cochlear implant condition. Linear regression analysis showed no predictive value of cochlear implant PTA, on reading comprehension when *variance* due to instructional age was removed. No relation with visual word recognition was found either (in all cases p >.05.). The threshold of hearing with an implant was not associated with reading skills.

Audiological profile

The auditory sensory system develops when it is stimulated and does not develop and even degenerates irreversibly when it is not activated (anymore).The condition of the system prior to implantation thus determines the capacities of the system to process the signal that is delivered by the implant. This means that the variables age at onset of deafness and duration of deafness will influence the auditory perception ability after implantation. In general the prognosis is better when the age at onset of deafness is higher and the duration of deafness is shorter (Miyamoto, Kirk, Svirsky & Shegal, 1999; Svirsky et al., 2004; Vermeulen, Snik, Brokx, Van den Broek, Geelen, & Beijk, 1997). When younger groups (or more homogeneous age groups) of children are studied this effect is not always found (e.g. Geers, Brenner et al., 2003). The additive effect of the two variables is a consequence of the enlargement of the period of maturation of the auditory sensory system (that is larger at a older age at onset of deafness) and of the restriction of the period of deprivation (that is also larger at a older age at onset of deafness and it is larger in case of a shorter duration of deafness). Furthermore, there is an interaction between these variables, because duration of deafness has a more negative impact when it concerns congenital deafness than it has when onset of deafness is at older ages. In congenital very profound deaf children auditory perception has been found to be limited in children that received an implant at a relatively high age (teenagers) (Snik, Makhdoum, et al., 1997). The level of hearing loss is also of influence on the development of the sensory system. In case of residual hearing the effect of (the length of) the period of deafness is smaller than in it is in case of total deafness.

Due to the additive effect of these variables and their interaction, the prognosis of auditory speech perception after cochlear implantation is difficult to quantify in a straightforward manner for the children who participated in our study (with varying ages at onset of deafness and long durations of deafness, especially in congenitally deaf children). In what follows we describe these variables for our population and present a classification system for their combined effect.

Both factors, age at onset of deafness and duration of deafness, showed a large variability in our group of participants with CIs (Par. 1.2). Children who received a cochlear implant at a relatively high age, and have had long periods of deafness, were included in the clinical programme.[1] Children with such audiological characteristics are not representative for the implant population nowadays. Moreover, our participants had very large pre-implant hearing losses, with a mean Pure Tone Average (PTA),[2] at the best ear, larger than 120 dB HL.[3] Table 2 shows the descriptives of the audiological variables and age at implantation and the Spearman rank correlation coefficients between them.

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1 This is due to the fact that the UMC St Radboud in Nijmegen commenced to perform surgery in children as one of the first teams in the world, in 1989. Cochlear implantation in relatively older children was considered essential in the beginning because these children were able to express their opinion about the quality of the sound and tuning of the implant device. At that time the effect of duration of deafness was not fully known yet.

2 The pure tone average (PTA) is the average hearing loss at 500, 1000 and 2000Hz.

3 In the first period that cochlear implantations were carried out, residual hearing was considered a contraindication for implantation, because the benefit of cochlear implants in children was not known yet and the possible loss of any residual hearing was avoided.

TABLE 2

Mean and range of age at onset of deafness, duration of deafness, and age at implantation, with Spearman rank correlations

Audiological Characteristics	*M*	Range	*R*s	
			age of onset of deafness	duration of deafness
age at onset of deafness (in months)*	13	0-74	1	-
Duration of deafness (in months)	61	16-140	-,57 **	1
age at implantation (in months)	74	27-146	,17	,62 **

** Spearman's rho correlation is significant at the .01 level

* Two children with progressive hearing loss were excluded from these computations, because the exact time of onset of profound deafness was unknown. The diagnosis of severe hearing loss had been confirmed before the age of six years.

The significant negative correlation of age at onset of deafness and duration of deafness shows that the children who became deaf at late age, had short durations of deafness, that is, children who became suddenly deaf at a later age, mostly due to meningitis or enlarged vestibular aquaduct (EVA), received implants at soon as possible. The significant positive correlation of duration of deafness with age at implantation reflects that children that received an implant at an older age had been deaf for a relatively long period. The absence of a significant correlation between age at onset of deafness and age at implantation is due to the fact that many congenitally deaf children received an implant at a relatively late age. Figure 1 shows the scatter diagram of the distributions of the latter two variables. Given the expected relations between age at onset of deafness, duration of deafness and level of speech perception skills after cochlear implantation we decided to group the individuals for these factors, in order to create a new ordinal variable 'audiological profile'. We developed a classification in which the two audiological variables were ordered according to their joint expected influence. The variable audiological profile comprised four levels that classified the order of expected benefit in terms of post-implant auditory speech perception.

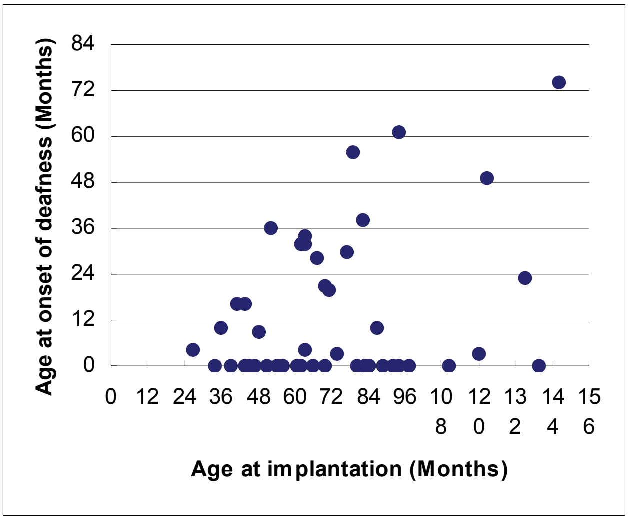

FIGURE 1 *Scatter diagram of the distributions of the variables age at onset of deafness and age at implantation*

Table 3 shows the descriptives of the variables on which the factor audiological profile was based. A combination of a congenital onset of deafness (0 months) and a long duration of deafness (> 72 months) provided the most poorly audiological condition for post-implant auditory perception. These unfavourable characteristics were classified at *audiological profile level 1*. Children with a pre-lingual acquired deafness (before the age of 36 months) and a long duration of deafness (> 36 months) were classified at *audiological profile level 2*. The congenital deaf children with duration of deafness of less than six years were classified at *audiological profile level 3*. The children with the best prognosis for auditory speech perception were classified at *audiological profile level 4*. This level comprised two subgroups: children with pre-lingual acquired deafness (36 months) with a duration of deafness of less than 3 years, and children with a progressive (mild or severe) hearing loss that had become profound deafness before the child had the age of 6 years. The duration of deafness of the children at 2 and 3 is similar. The order of these two levels was determined by the fact that meningitis (which was the most common cause of deafness in this group) was likely to have caused damage to the higher neural structures and that therefore the children with acquired deafness would perform less well on speech perception tasks.

TABLE 3

Number, mean and SD of age of onset of deafness and duration of deafness and SD, for audiological profile factor levels (1 to 4)

Audiological profile level	1	2	3	4
Number of children	13	8	13	16
Type of aetiology	Congenital	Acquired pre-lingual	Congenital	Acquired prelingual or progressive
Mean age at onset (months)	0	15 (11)	0	41(26)
Mean duration of deprivation (months)	95 (17)	51 (14)	54 (11)	41 (27)

The division of congenital deaf children into an older and younger group with a duration of deafness of less or more than six years, is partly based on the inclination to form equal groups. Though in congenital deaf children a older age at implantation is associated with more poorly results, there is not one specific age at implantation that shows a significantly less performance (Snik, Makhdoum, et al., 1997).

The effect of audiological profile on reading was analysed by two analyses of variance (with instructional age as a covariate). First we analysed the effect on the dependent variable reading comprehension and the other on visual word recognition. There was an interaction between the factor and the covariate, resulting in different slopes. Therefore an analysis of based on within factor-level covariances was carried out. We found a significant effect ($F(3,42) = 4.87$, $p = .005$) of audiological profile on reading comprehension. Table 4 shows the descriptives per audiological profile level. Pairwise comparisons between the estimated mean reading comprehension scores of the audiological profile levels showed a significant better performance of level 4 over level 1 only (mean difference = -4.91, $p = .004$).[4] The other differences were not significant.

[4] In all pairwise comparisons in chapter 3 Bonferroni adjustments for multiple comparisons are used.

TABLE 4

Number, estimated marginal means for reading comprehension score (controlled for instructional age), observed mean reading comprehension score and standard deviation, per audiological profile level

Audiological Profile	*N*	Estimated Mean	Observed Mean	*SD*
level 1	13	23.71	24.48	5.14
level 2	8	27.49	28.14	5.90
level 3	13	24.79	22.21	4.09
level 4	16	28.62	29.77	3.42

The second analysis of covariance showed that there was no effect of audiological profile on visual word recognition. In conclusion, these analyses showed that audiological profile influenced reading comprehension, the level with children with the most poorly prognosis with respect to auditory speech perception had the lowest reading scores, no such effect was found on visual word recognition.

3.2.2 Environmental variables

We first examined the effect of the factor educational setting and second, the effect of the factor emphasis on auditory approach (in the home and the school situation separately) on reading comprehension and on visual word recognition.

Educational setting

In the Netherlands deaf children are mainly educated in one of three different settings and therefore, the variable educational setting is a factor with 3 levels: the first level is *deaf education* (special education for deaf children); the second level is *hard-of-hearing education* (special education for hard-of-hearing children) and the third level is *mainstream education* (regular education). The educational setting of a child was evaluated at several points in time, including the setting before implantation when the children applied for cochlear implantation and the setting at the time of our reading assessment. Table 5 shows the percentage of children in each educational setting at these two different evaluation moments in follow-up. Before implantation the majority of children was educated in education for the deaf. Fewer children were in education for the hard-of-hearing and only two children were in mainstreamed settings. A gradual shift of children from deaf to mainstream education was observed after implantation. In about one-third of the cases this shift took place via temporarily placement at schools for the hard-of-hearing. Consequently, the total percentage of children were, after at least three years post implantation in this hard-of-hearing setting was comparable to the percentage of children that were in that setting before implantation, but these were not the same children.

TABLE 5

Percentages of children at the educational setting factor levels, at two evaluations during follow-up

Educational setting	Pre-implant	At reading assessment
Deaf	74	34
Hard-of-hearing	22	18
Mainstream	4	48

The effect of educational setting, pre- and post-implant, on the reading comprehension and next on the visual word recognition was determined with analyses of variance with instructional age as a covariate. In both analyses there were no factor-covariate interactions. First, the pre-implant educational setting showed no effect on post-implant reading comprehension and no effect on visual word recognition. However, at the evaluation period after at the time of our reading assessment, at least at 36 months post-implant, we found a significant effect of educational setting on reading comprehension ($F(2,46) = 8.57$, $p = .001$). Table 6 presents the descriptives, per educational setting at the time of our reading assessment. The highest means were observed for children in mainstream settings, the lowest for children in deaf education. Pairwise comparisons showed that at least more than three years post-implant, the children in deaf education were performing poorer than those in mainstream education (mean difference = -5.83, $p = .001$) and that children in education for the hard-of-hearing were also performing more poorly than those in mainstream education (mean difference = -2.68, $p = .044$). Though educational setting did influence reading comprehension post-implant, we found no such effect on visual word recognition.

TABLE 6

Number, estimated marginal mean reading comprehension scores (controlled for instructional age), observed mean scores and SD per educational setting at the time of our reading assessment

Educational setting	*N*	Estimated Mean	*M*	*SD*
Deaf education	17	23.88	23.53	5.42
Hard-of-hearing	9	24.81	24.45	4.41
Mainstream	24	28.29	28.68	4.63

Emphasis on auditory approach at school and at home

Detailed information about the emphasis that is placed on auditory approach had been collected within the frame of the rehabilitation of the children in the implant programme. The auditory approach was categorized into three levels: *limited* emphasis placed on auditory approach, *moderate* emphasis on auditory approach, and *predominantly* auditory approach. The auditory-verbal demand made on the children was rated by the CI team psychologist and the CI-team coordinator. It was a quantification covering the period from the time of implantation through three years post implantation. The emphasis on auditory approach offered to the child was rated for the school situation as well as for the approach at home. In the school situation the rating was a judgment of the emphasis on auditory-verbal communication by the teacher and the speech therapist. For the evaluation of the home situation it concerned the general degree of auditory-verbal communication in every day situations, by all family members. Table 7 shows the descriptives of emphasis placed on auditory approach, per factor level. ANCOVA of the effect of these factor, with instructional age as a covariate, on reading comprehension showed that the emphasis placed at school on the auditory approach to the child, in the first years after implantation, showed a significant effect on the reading comprehension scores ($F(3,46) = 7.49$, $p = .002$). Pairwise comparisons showed significant differences between the means of the moderate and the predominant level (mean difference = -4.39, $p = .001$). (The absence of a significant difference under limited versus predominant emphasis on auditory approach in the school situation is probably due to the small number of children at the 'limited' level.)

TABLE 7

Number, estimated marginal mean reading comprehension scores (controlled for instructional age), observed mean scores and SD, per level of auditory approach at home and at school

	Auditory approach at home				Auditory approach at school			
	N	Estimated Mean	Observed Mean	*SD*	*N*	Estimated Mean	Observed Mean	*SD*
Limited	14	24.08	23.13	6.16	4	27.31	28.56	6.11
Moderate	10	24.58	24.65	5.78	14	23.02	22.48	5.39
Predominantly	26	27.90	28.39	3.69	32	27.40	27.48	4.60

The emphasis on auditory approach in the home environment also showed a significant effect on the reading comprehension scores ($F(3,46) = 5.95$, $p = .005$). Pairwise comparisons showed significant differences between the means of the limited and the predominant level (mean difference = -3.82, $p = .010$), and moderate and predominant level (mean difference = -3.33, $p = .029$, one-tailed test). We found no effect of either, emphasis that was placed on an auditory approach in the school or in the home environment, on visual word recognition, however.

3.2.3 Conclusions

Remarkably we found no effects of audiological and environmental factors at all on visual word recognition while there were effects of all audiological and environmental factors, except the pre- implant educational setting, on reading comprehension. The absence of a relation with visual word recognition will be discussed in the Discussion (Par. 3.6). What follows here concerns only reading comprehension.

First, we studied audiological variables and their direct association with reading comprehension. We showed that cochlear implantation caused a significant improvement in the hearing capacity of the participants in our study. Their pure tone average with CIs was significantly better than that with conventional hearing aids. This effect was present shortly after implantation, within only 6 weeks of implant use. Next we observed, as expected, that the thresholds of hearing with CIs were not associated directly with the reading comprehension scores. However, there was an effect of the expected post-implant speech perception performance on reading comprehension. Children with the best prognosis for post-implant auditory speech perception benefit, that is, auditory profile level 4 showed better reading skills than those at level 1. This indicates that auditory speech perception skills might contribute to the reading skills of deaf children with CIs.

The second group of variables that was included in our study included the characteristics of the child's home and school environment. The pre-implant educational setting showed no effect on the reading comprehension scores. After implantation many changes in the educational placement of the children have taken place. At time of the reading evaluations, at least at 36 months post-implant, placement in education for hard-of-hearing children and in mainstream settings had a positive effect on reading comprehension skill. As to what in other studies is often labeled 'communication mode' we found that the use of an auditory approach had a positive effect on reading comprehension. This holds for the approach that is employed in the school situation as well as for the one in home situation.

In conclusion, we found that the reading comprehension level after implantation was not only determined in a direct manner by the post-implant audiological and environmental factors. The improvement of the threshold of hearing resulting from cochlear implantation is expected to lead to improved auditory speech perception and to provide access to spoken language. The joint effects of audiological and environmental factors on auditory speech perception and on language skills were expected to facilitate reading comprehension.

3.3 Speech perception

In this paragraph we study the development of auditory speech perception skills after cochlear implantation and the association with reading skills. Par. 3.3.1 analyses the auditory perception development over time after implantation. Furthermore the association between reading skills and the post-implant auditory perception skills is investigated. Par. 3.3.2 analyses relations between scores on different auditory speech perception tests. In Par. 3.3.3 the effects of audiological and environmental characteristics on the auditory speech perception factor are investigated. Par. 3.4 presents the conclusions about the association between reading skills and auditory speech perception skills.

3.3.1 Association between reading and auditory speech perception

Two tests were used to assess auditory speech perception skills. One test was administered as part of the standard procedure in the clinical implant evaluation programme of Cochlear Implant Centrum Nijmegen/Sint-Michielsgestel, the other test was administered only once. The Gestel-Nijmegen test (GN-test), an auditory speech perception test, was administered before implantation and post-implant, at yearly intervals (12, 24 and 36 months post-implant). For the children that received an implant most recently the 36 month evaluations were in the same year as the reading comprehension test. These 36 month evaluations have taken place at most 8 years prior to our reading assessment (in 2002) for the other children. The second test, the auditory consonant discrimination task, was specifically developed for the purpose of this study. This test was administered once, between 2001 and 2002. This assessment took place between after 3 to 11 years of implant use, dependent of the year at which the cochlear implantation took place. Both tests were administered by experienced staff of the Cochlear Implant Centre. The tests, the administration protocol and the development of auditory speech perception are described. Furthermore we analyse the relation between reading skills and auditory speech perception.

Auditory speech perception skills

The Gestel-Nijmegen Speech Perception Test that was used to assess pre- and post-implant auditory speech perception skills, partly a Dutch adaptation of the ESP test of Moog and Geers (1990), (GN-test, Snik, Vermeulen, Brokx, et al., 1997). The test battery consists of nine subtests that cover a wide range of levels of complexity. The subtests differ in the complexity of the stimulus material and in the level of the task that has to be performed. The simplest level consists of discrimination between two words that differ at a supra-segmental level (For example the judgement of similarity between the spoken words /elephant/ and /bal/). The most difficult level is open set speech recognition of monosyllabic CVC’s, that require a verbal repetition of the perceived item as a response. (For example: imitation of the word /bus/). There are two scores of the GN-test that were used in our study; the *equivalent hearing loss value* (EHL) and the *open set phoneme recognition score* (PS). These scores are described below.

Auditory speech perception expressed as equivalent hearing loss

Equivalent hearing loss values (EHL) in dB HL, refer to auditory speech perception levels of deaf children with conventional hearing aids. The equivalent hearing loss concept was developed to quantify auditory speech perception of cochlear implant users in terms of hearing loss of conventional hearing aid users that perform at a similar level (Boothroyd & Eran, 1994). Snik proposed this measure in a method for longitudinal follow-up of improving performance assessed with several different subtests over time (Snik, Vermeulen, Brokx, et al., 1997). For EHL calculation first the subtests are categorised into three levels of complexity. The scores at two 'low level' auditory tasks (supra segmental discrimination and closed set supra segmental word identification) were converted into the Basal Speech perception score (BS). The scores at a higher level of complexity (closed set monosyllable and spondee identification tasks) were used to determine the Word Identification score (WI). We used the word score (OS) from the test at the highest level (open set monosyllable recognition). Normative data of the BS, WI and OS scores of children with conventional hearing aids educated in an aural-oral school for the deaf and in a school for the hard-of-hearing, in the Netherlands, were used to derive equivalent hearing loss values for each of these three levels of complexity. The mean EHL value then was computed. The reference group of conventional hearing aid users had hearing losses ranging from 120 to 70 dB HL. These hearing losses therefore defined the upper and lower limit of the EHL values. The advantage of the use of EHL values instead of raw tests scores was that a broad range of speech perception skills could be assessed and expressed in one and the same measure, without floor or ceiling effects as a consequence of test difficulty. The use of EHL values enabled us to compare pre-implant performance, when the perception skills were still limited and in many cases only apparent in supra-segmental discrimination tasks, with the most difficult task, open set speech recognition. It is important to note that a *lower* equivalent hearing loss value expresses *better* speech perception ability.

In order to evaluate the effect of cochlear implantation on auditory speech perception, expressed in EHL, we computed the mean values of the pre-implant and 12, 24 and 36 months post-implant EHL values and carried out paired sample t-tests to determine the difference between mean scores at consecutive yearly evaluation sessions. Table 8 and Figure 2 summarise the relevant data.

TABLE 8

Number, mean EHL values and SD, pre-implant and at 12, 24 and 36 months post-implant

Evaluation moment in time	*N*	*M*	*SD*
Pre-implant	50	121	5.54
12 months post-implant	49	98	17.80
24 months post-implant	49	86	13.30
36 months post-implant	49	82	12.61

The auditory speech perception skills of the children with CIs were pre-implant, on average, at the level of deaf children with hearing loss of 120 dB with conventional hearing aids. That is, they performed similar to very profound deaf hearing aid users, without residual hearing. Their mean EHL values gradually improved, reflected by a decreasing mean, to a level of speech perception that is comparable to that of severely deaf hearing aid users, with a hearing loss of 80 dB. Except for the pre-implant outcomes, where there was a ‘ceiling effect’, there were large individual differences however.

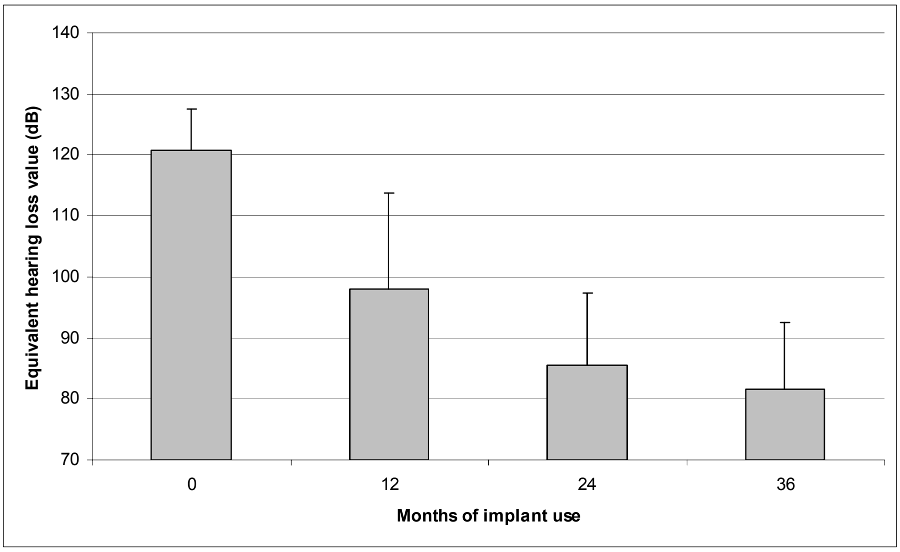

FIGURE 2 *Mean equivalent hearing loss values and SD, pre-implant (0) and at 12, 24 and 36 months post-implant*

Paired sample t-test showed that the differences between the means of two consecutive follow-up evaluations were significant (0 versus 12 months: $t(48) = 8.85$, $p = .000$; 12 versus 24 months: $t(48) = 7.27$, $p = .000$; 24 versus 36 months: $t(48) = 3.40$, $p = .001$). We conclude that at least until 36 months after cochlear implantation, the EHL values of the children improved every year. These results are similar to those reported in literature, as mentioned in the Introduction section.

Next we carried out linear regression analyses to investigate the association between reading skills and EHL. In the first analysis reading comprehension was the criterion, and in the second visual word recognition. In both analyses the first predictor was instructional age and in a second stage effects of the predictors EHL at the four pre- and post-implant evaluation times were analysed stepwise. We found that after variance due to instructional age was removed, EHL (Beta = -.27, $t = -2.65$, $p = .011$[5]) accounted for 8% of the variance in reading comprehension, which implies that the auditory speech perception skills expressed in EHL are explaining variance in reading comprehension to a small extent. Surprisingly, we found no association between visual word recognition and EHL at 36 months post-implant. We conclude that auditory word recognition showed a weak association with reading comprehension but not with visual word recognition.

Auditory Speech Perception expressed as phoneme score

Speech perception was evaluated with the Open Set test of the Gestel-Nijmegen speech perception test battery, which is the most difficult subtest. The subjects had to repeat monosyllables (CVC construction), that were presented via audition. The score consist of the percentage phonemes that were correctly repeated. The pre- and post-implant mean phoneme scores (PS) are summarized in Table 9 and Figure 3.

5 A decreasing EHL expresses an improvement in auditory speech perception, and leads to a negative Beta value.

TABLE 9

Number, mean phoneme scores and SD, pre-implant and at 12, 24 and 36 months post-implant

Phoneme score	*N*	*M*	*SD*
Pre-implant	8	8.75	12.46
12 months post-implant	30	55.10	24.74
24 months post-implant	44	62.23	22.80
36 months post-implant	45	72.13	21.92

At the pre-implant assessment only 8 of the 50 children were able to perform the task. The open set task appeared too difficult for children with almost no auditory perception skills. The missing scores of many children in fact were extreme low scores. Furthermore, the limited intelligibility of the speech of the deaf children, especially before implantation, complicated interpretation of their verbal responses. For that reason standardised assessment of the speech perception of the children, with this subtest often was not possible until at least one year after implantation. Due to the limited number of observations, the pre-implant score is not used in further analyses.

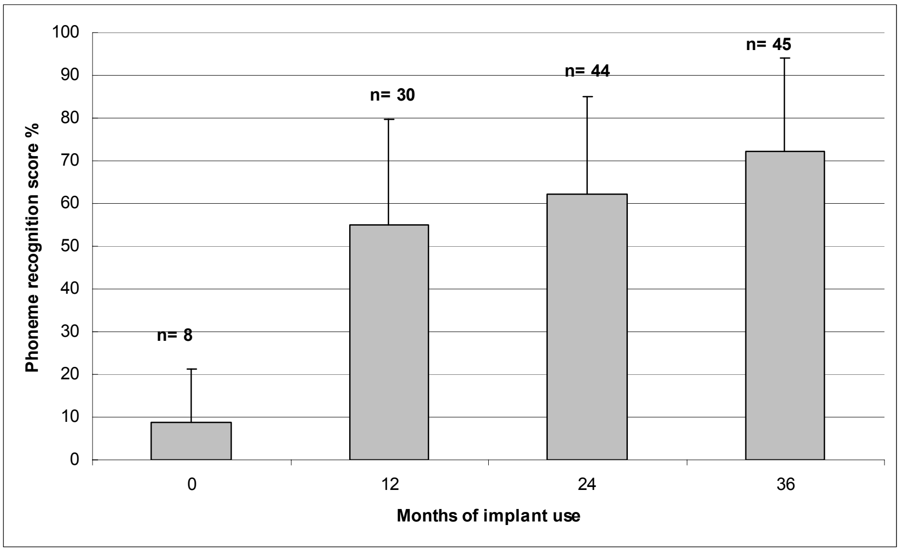

FIGURE 3 *Mean phoneme scores and SD, pre-implant and at 12, 24 and 36 months post-implant*

The mean pre implantation speech perception score therefore can safely be estimated to be lower than 9%. Paired sample t-tests showed that the differences between the means of two consecutive follow-up evaluations were significant (0 versus 12 months: $t(6) = -6.60$, $p = .001$; 12 versus 24 months: $t(28) = -4.86$, $p = .000$; 24 versus 36 months: $t(40) = -2.60$, $p = .013$). At least until three years after cochlear implantation the average phoneme score improved every year, to an average of 72%. There was a considerable variation however, at each follow-up evaluation. In other studies similar results have been reported. Dowell, Blamey and Clark (1995) found 60 to 80% open set word recognition. Geers (2003) found 50%, on stimuli that included also low frequency words. The speech perception of our population appears to develop similar to that of other implant users.

In the first linear regression analysis we carried out, reading comprehension was the criterion and in the other visual word recognition. In both analyses the first predictor was instructional age and in a second stage, effects of the predictors phoneme score at three post-implant evaluations (12, 24 and 36 months) were analysed stepwise. No association of reading comprehension with the phoneme score was found. No association of visual word recognition was found with the phoneme score. The auditory recognition of spoken phonemes did not show a relation with reading skills.

Auditory consonant discrimination

The second auditory speech perception test in our study was an Auditory Consonant Discrimination task (ACD). This task was developed and constructed specifically for the purpose of this study for two reasons. First, we wanted to assess auditory speech perception at the time of the reading evaluations. The Gestel-Nijmegen test was only used until 36 months after implantation only, and by 2002, when the reading skills were evaluated, some children used their implant for 11 years. The second reason was that we wanted to assess the auditory perception of phonologically significant speech contrasts (distinctive features), such as, voicing, place and manner of articulation. The task had to be suitable also for deaf children with limited speech intelligibility. Therefore the task involved a manual (instead of a verbal) response. The response had to be given by pressing a ‘same’ or ‘different’ button on a button box. The children had to judge whether stimuli words that were presented via audition contained the same or different phoneme as an initial phoneme in a target-word. In order to minimise the role of the memory, a picture of the target word was presented visual when the items were presented via audition. For example the target phoneme (in this example a consonant) was /b/, the picture presented visually was ‘bed’, the alternative words, presented auditory, were /bed/, /wet/, /vet/, /net/, etcetera. Every word that contained a target phoneme was presented three times at random, mixed with seven other alternative existing words which differed only from the target word with respect to the target phoneme. This auditory consonant discrimination task (ACD) was administered, via a computer, in a sound proof room individually at the audiological centre of the Implant Centre. Reaction times (latencies) and accuracy were measured and feature confusions were registered.

Because the auditory consonant discrimination task was administered only once, no development could be monitored. In order to obtain a more robust dataset we pooled the accuracy and latency data. The Spearman rank correlation, between the median latencies and the number of correct responses was $r_s = -.56$, $p < .001$. This implies that the participants performed above chance level and they did not show a speed-accuracy trade-off (rapid but inaccurate responses). Subjects were responding rapidly and correctly or they were responding slow and tended to make more mistakes. In our opinion these findings justified the pooling of data. Figure 4 shows the scatter diagram of the latencies of correct responses and the number of correct responses.

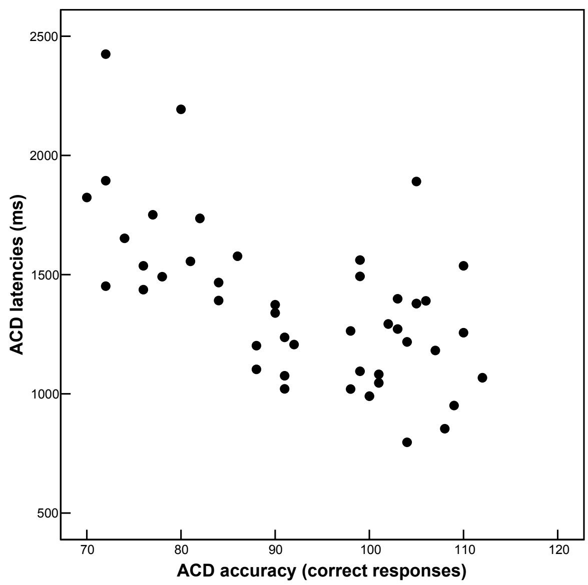

FIGURE 4 *Scatter diagram of accuracy (x-axis) and latencies (y-axis) of ACD responses*

For the pooling of the scores first the median latencies and the number of correct responses were converted into *z* scores. The sign of the latency *z* scores was changed because a longer latency corresponds with a lower performance. Next the reaction time and accuracy *z* scores were averaged. This average ACD performance followed a normal distribution (Shapiro Wilk statistic = .950, $df = 46$, $p = .05$). The 'average' ACD was used in further analyses.

We analysed the association of the reading skills (reading comprehension and visual word recognition) with the ACD data. Two linear regression analyses, one with reading comprehension scores and the other with visual word recognition scores were carried out. In both analyses the first predictor was instructional age and the second predictor the ACD. We found that ACD accounted for 11% in the variance of reading comprehension scores (Beta = .34, $t = -3.28$, $p = .002$), after variance due to instructional age was removed. The auditory speech perception skills expressed in ACD were explaining variance in reading comprehension to a limited extent. No association was found, between ACD with visual word recognition, however. These findings were similar to those of the auditory speech perception tests that were performed 36 months post-implant.

3.3.2 Underlying factors in auditory speech perception outcomes

We carried out a principal axis factor analysis with the scores on the three auditory speech perception tests; the equivalent hearing loss values and the phoneme scores at 36 months post-implant (because at that time in follow-up they had the strongest association with reading comprehension) and the auditory consonant discrimination scores, to investigate whether we could identify a common factor. We assessed the association of reading comprehension with this factor and verified whether there was a relation between this factor and visual word recognition. Our analysis extracted one factor with an Eigenvalue over 1. This factor can be identified as an 'Auditory Speech Perception' factor that explained 77% of the variance. The equivalent hearing loss value and phoneme score showed the highest factor loading and the auditory consonant discrimination had a slightly lower loading. Table 10 shows the factor loadings. This factor will be referred to as Auditory Speech Perception (ASP).

TABLE 10

Auditory speech perception tests and factor loading of principal axis factoring

Test score	Factor loading
EHL 36	-0.96
PS 36	.90
ACD	.77

Linear regression analyses were carried out to investigate the association between the reading skills and this ASP. In one analysis reading comprehension was the criterion, and in the other visual word recognition. There was a significant but weak association between reading skills and ASP (F = (2,41) = 20.84, p = .000). After variance due to instructional age was removed (Beta = .29, t = 2.66, p = .011). ASP accounted for 9% of the variance in reading comprehension. As in the analyses of the association of visual word recognition with the scores at the three auditory speech perception tests separately, no association of visual word recognition with ASP was found.

In Par. 3.3.3 ASP is used to assess the relation between audiological and environmental variables and auditory speech perception abilities after at least 36 months post cochlear implantation, which is described in the next paragraph. In order to determine whether instructional age should be included as a covariate in these analyses we assessed whether it was associated with ASP. There was no statistical association (R = .01, p = .97).

3.3.3 Audiological and environmental variables

In this paragraph the effect of audiological and environmental factors on ASP is analysed. Instructional age was not entered as a covariate in the analyses of variance because linear regression analyses showed no association between instructional age and ASP.

The above-mentioned analyses of ASP concern long-term achievements, that is, assessment took place between 3 to 8 years post-implant. We were also interested in the effects of the factors in the pre-implant situation, in order to verify whether possible effects could be attributed to cochlear implantation. We cannot study the pre-implant scores with ASP, because it is a computation based on long-term speech perception abilities. The only pre-implant speech perception scores that were available for a large number of children were the equivalent hearing loss values. Therefore in some analyses the EHL values are used instead of the ASP.

The effect of audiological profile on auditory speech perception

The audiological variables age at onset of deafness and duration of deafness were expressed by a new variable: audiological profile. This factor had four levels (Par. 3.2.1). Audiological profile was expected to show a strong association with post-implant speech perception skills, with an increasing performance at higher profile levels. Table 11 and Figure 5 show the descriptives.

TABLE 11

Number, mean and SD of the Auditory Speech Perception factor, per audiological profile level

Audiological profile	*N*	*M*	*SD*
Level 1	10	-0.95	0.71
Level 2	7	-0.49	1.15
Level 3	12	0.21	0.61
Level 4	15	0.79	0.28

ANOVA shows a significant overall effect ($F(3,40) = 15.50$, $p = .000$) of audiological profile on ASP. Pairwise comparisons showed significant differences between audiological profile level 1 versus 3 (mean difference = -1.21, $p = .003$), level 1 versus 4 (mean difference = -1,74, $p = .000$) and level 2 versus level 4 (mean difference = -1.27, $p = .001$). As expected the mean scores for the groups with the better prognoses based on audiological characteristics were higher than those for children with more unfavourable audiological profiles.

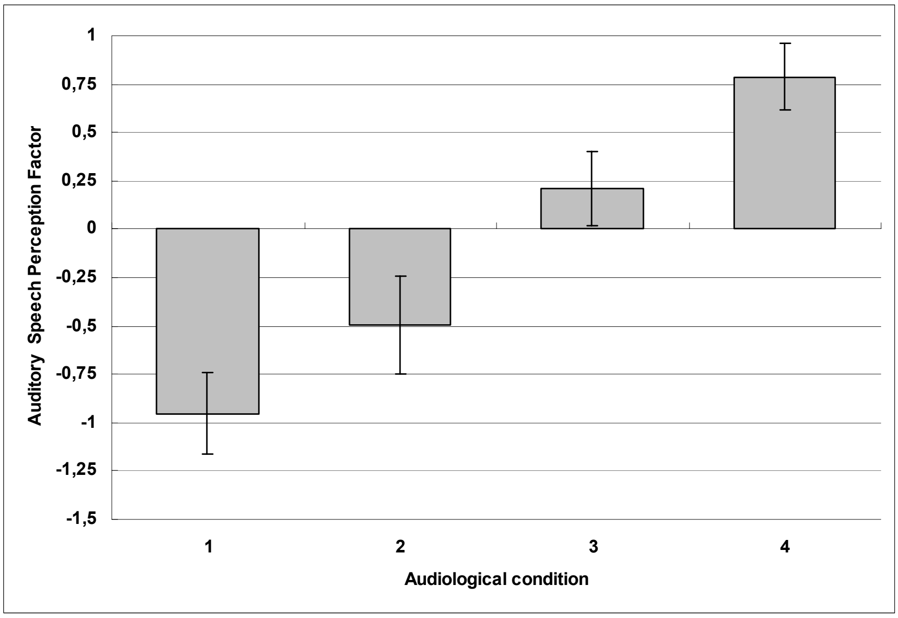

FIGURE 5 *Mean and SD of Auditory Speech Perception scores per audiological profile level*

Next we compared the effect of audiological profile on auditory speech perception pre-implant and at least 36 months post-implant. As reported in the introduction we used the EHL values as dependent variable (instead of ASP) in these analyses. An ANOVA did not show an effect of audiological profile on pre-implant EHL values. After implantation the EHL at 36 months had improved as a consequence of the implantation and a significant effect of audiological condition on EHL was found.[6] Figure 6 depicts the mean EHL values. Figure 6 illustrates that before implantation, with the use of conventional hearing aids audiological profile did not influence speech perception. When the children used implants for 36 months there was such an effect, as expected. Children who had a sensory system that was relatively well developed before implantation had better post-implant speech perception capacities. With hearing aids, before implantation, these perception capacities have not been developed, notwithstanding the fact that the children have had auditory training for several years.

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6 A significant overall effect ($F(3,45)=11.59$, $p=.000$). Pairwise comparisons showed significant differences between audiological profile level 1 versus 3 (mean difference = 12.81, $p=.013$), level 1 versus 4 (mean difference = 19.18, $p=.000$) and level 2 versus level 4 (mean difference 17.88, $p=.001$). These effects were similar to the effects on the ASP Factor.

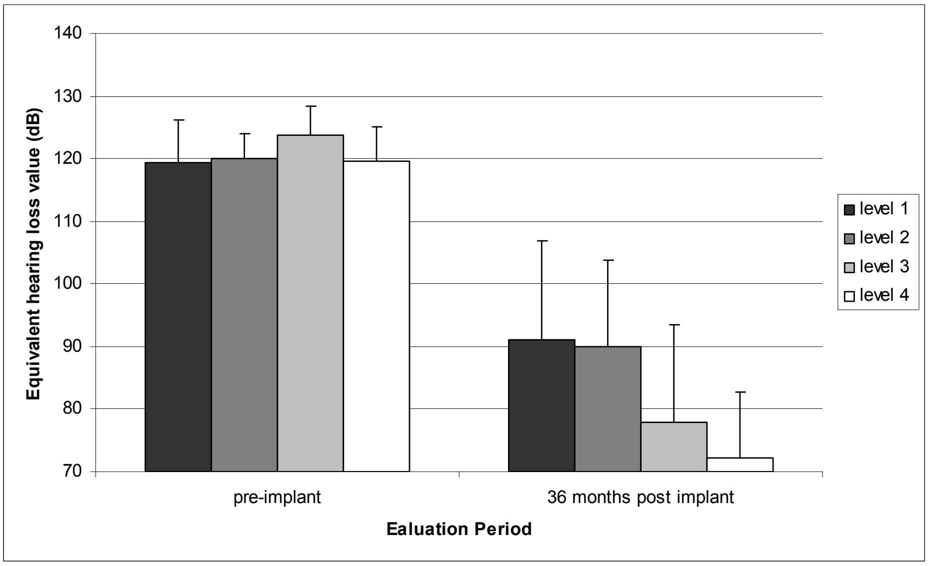

FIGURE 6: *Mean equivalent hearing loss values, per audiological condition, pre-implant and 36 months post-implant*

Effects of environmental factors on auditory speech perception

Educational setting

The effect of educational setting on ASP was investigated with an ANOVA. Although educational setting was determined at several points in time, we chose to use the factor educational setting at 36 months post-implant, because ASP included two measures that were carried out at 36 months post-implant and the other after at least 36 months post-implant. Table 12 summarizes the descriptives per educational setting.

TABLE 12

Number, mean and SD of the Auditory Speech Perception factor, per educational setting, at 36 months post-implant

Educational setting 36 months post-implant	*N*	*M*	*SD*
Deaf education	18	-0.55	0.88
Hard-of-hearing education	10	0.25	0.90
Mainstream education	16	0.55	0.68

ANOVA showed a significant effect of educational setting on the ASP *(F(*2,41) = 7.81, *p* = .001). The pairwise comparisons showed that 36 months post-implant the children in deaf education were performing poorer than those in education for the hard-of-hearing (mean difference = -0.79 *p* = .018 (One-tailed test) and than those in mainstream education (mean difference = -1.09, *p* = .001). No significant difference between the speech perception of children in hard-of-hearing and those in mainstream education was found.

To gain further insight in the effect of educational setting on auditory speech perception we studied that relation pre-implant, and at 36 months post-implant. For this comparison we used EHL values instead of ASP again. ANOVA showed no effect of the pre-implant educational setting on pre-implant EHL values. In contrast, 36 months post-implant there was a significant effect.[7] Pairwise comparisons showed significant differences of the means in deaf education with those in hard-of-hearing and those in mainstream education. Figure 7 shows the mean EHL values.

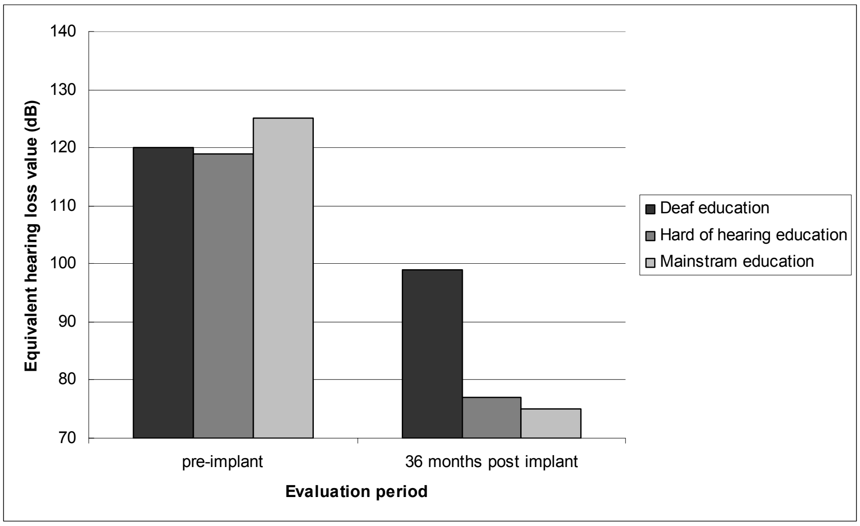

FIGURE 7*:* *Mean equivalent hearing loss values, per educational setting, pre-implant and 36 months post-implant*

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7 A significant overall effect (*F*(2,46)=10.35, *p*=.000). Pairwise comparisons were similar to the ones on the ASP Factor.

We conclude that children who are 36 months after implantation in educational settings for hearing or hard-of-hearing children tended to have better auditory speech perception skills. Placement in these settings before implantation had no effect on the speech perception of children (who had hearing aids at that time). However, this concerned only a few children.

Emphasis on auditory approach at home and at school

The effect of emphasis on auditory approach at home situation and next in the school situation on auditory speech perception was investigated with ANOVA with the ASP as the dependent variable. Table 13 summarises the descriptives.

TABLE 13

Number, mean and SD of Auditory Speech Perception score , per category of auditory approach, at home and at school

	Auditory approach at home			Auditory approach at school		
	N	*M*	*SD*	*N*	*M*	*SD*
Limited	11	-0,69	.91	2	-0.76	0.92
Moderate	9	-0,21	.86	13	-0.53	0.91
Predominantly	24	0.46	.76	29	0.34	0.84

We found an effect of emphasis on auditory approach at home on ASP $(F(2,41) = 7.97$, $p = .001)$. The pairwise comparisons showed that if at home communication was predominantly auditory based children were performing better than with a limited auditory approach (mean difference = -1.16, $p = .001$). The performance of children from home environments where a moderate level of auditory based communication was used was in between the other two levels. In the school environment we also found an association $(F(2,41) = 5.45$, $p = .008)$. Pairwise comparisons showed that children in a school environment that approached the children predominantly in an auditory based manner performed better than those in environments with a moderate auditory based approach (mean difference = -0.87, $p = .013$). The absence of a difference between the levels limited and predominantly was the consequence of the small number of observations for the limited level of this factor.

3.3.4 Conclusions

Auditory speech perception assessed with tests that were performed pre-implant and yearly post-implant showed significant improvements over time. Speech perception in profoundly deaf children with CIs after implantation is comparable with that in children with a severe hearing loss (between 70 to 90 dB). Open set phoneme recognition in monosyllables showed a similar improvement over time. After 36 months of implant use children, on average, perceive 72% of the phonemes of monosyllables correct. Such a level of speech perception of deaf children must be considered exceptional for profoundly deaf children and can be attributed to the use of CIs only. Before implantation these good levels of speech perception were not reached, notwithstanding the fact that the children have had auditory training/speech therapy. The factor analysis showed that there was a strong relation between auditory speech perception outcomes that were measured with different instruments, at consecutive moments in follow-up. There was an effect of audiological profile on post-implant auditory speech perception. Children with the least prognosis indeed performed poor. The order of the factor levels was reflecting the quality of post-implant auditory speech perception skill (level 4 worst, level 1 best). Furthermore, children that were educated in mainstream or hard-of-hearing settings showed the best post-implant speech perception skills. Pre-implant there was no such difference. All speech perception scores (including ASP) after more than 36 months post-implant had a statistically significant relation with reading comprehension. However, their contribution to explained variance in reading comprehension was only small. No associations of visual word recognition with auditory speech perception with were found. The visual recognition of written words, quantified by accuracy in a lexical decision task shows no relation with the auditory word recognition as measured with speech perception tasks.

The conclusions regarding auditory speech perception will be further discussed in the Discussion (Par. 3.6).

3.4 Language skills

We studied three language components in the Simple View of Reading model that were expected to contribute to reading comprehension and to visual word recognition. The first two are language comprehension components (receptive vocabulary and morpho-syntactic competence). The third is phonological skill in text decoding.

There was only a limited choice of appropriate language assessment instruments for our participants. The tests we used for language assessment were selected partly based on practical issues. First, the use of tests developed for hearing children in deaf children of course has its limitations. This is due to the fact that language tests that involve spoken stimuli also reflect a part of the child's speech reading and auditory speech perception skills. Furthermore, the spoken language skills of deaf children are often substantially lower than those of their hearing peers. Second, only a limited number of standardized tests for deaf children, with normative data for deaf children, are available. We, therefore, used data on language development that were available already, as well as data that were collected specifically for our study. The available data were data that had been collected within the frame of the clinical follow-up of the implant programme. One of the language assessments that had been carried out in the implant programme, was the assessment of receptive vocabulary of spoken language. The data collected pre-implant and after 12, 24 and 36 months post-implant were available. Another test that we used was presented by its authors as suitable for assessing (written) morpho-syntactic competence of deaf Dutch children in the age range of 7 to 20 years. This test was administered for research purposes only, at the same time as the reading evaluations (in 2002). Furthermore we assessed the access to phonology in text decoding (phonological skill) of the children with CIs. We constructed a specific test because no suitable test for Deaf Dutch children was available.

In Par. 3.4.1 we describe the receptive vocabulary, the morpho-syntactic competence and the phonological skill of the children with CIs. In addition, we explore the relation of these variables with reading skills. Par. 3.4.2 analyses relations between scores on different language tests. In Par. 3.4.3 we study the effect of audiological and environmental variables on language comprehension skills, and on phonological skill.

3.4.1 Associations between reading and language skills

In this paragraph the three language components are evaluated. First, the development of the receptive vocabulary in the first three years after cochlear implantation is investigated and next the morpho-syntactic competence is studied. Furthermore the associations of reading comprehension and visual word recognition with these two language comprehension components are explored. Second, phonological skill is studied and associations of reading skills with post-implant phonological skill are explored.

Receptive vocabulary

We evaluated the receptive vocabulary with two tests. Depending on the age and general language level of the child,[8] either a Dutch version of the Reynell Developmental Language Scales (Reynell, 1977) or the Taaltests voor Kinderen (Language Tests for Children, Van Bon, 1982) was used to assess the receptive vocabulary. Both tests are standardized test procedures and have norm data for hearing children. The use of standard scores was not possible, because most participants would be lumped at the lower end of the scale. Instead receptive vocabulary age equivalent (RVAE) scores were used in further analyses. (These are scores that express the age of children in the norm group that have the same vocabulary size.) The stimuli are in spoken language and the responses are non-verbal in both instruments. The tests were administered before implantation and consecutively each year, up to 36 months after implantation. Pre implant only 24 of the children were able to complete the test because they had a spoken language level that enabled them to complete the receptive vocabulary test. For some children auditory perception skills were so poor (even with support of speech reading) that they could not perceive the stimuli via audition. The results that were obtained pre-implant, therefore, are the scores of the best performing children. The other 26 children would have obtained even lower scores. Not all participants performed the test every year. At 24 months during follow-up 7 children were not tested and at 36 months 10 children were not. In most cases this was due to practical reasons, for example because a child was ill, or the parents were not able to accompany the child to a certain evaluation session in follow-up. We corrected for the missing data in the 24 and 36 month data sets, to obtain a more robust sample for further analyses. We used estimates based on linear regression analyses of the available data. (Common methods like the 'Nearest Neighbour method' were not appropriate in this case, due to the large variability and the limited number of scores.) By linear regression analyses we determined the regression of the scores at 24 months post-implant on scores at 12 and 36 months after implantation and of scores at 36 months after implantation on scores at 12 and 36 months. Table 14 shows the relations between scores on receptive vocabulary measures that took place at different times during follow-up.

8 The language levels were available from previous assessments (or observations) within the frame of the guidance of the children at their schools or within the implant centre.

TABLE 14

Beta, correlations and explained variance of receptive vocabulary predictors on receptive vocabulary at 24 and on 36 months post-implant

	Beta	*R*	R^2
Criterion variable: receptive vocabulary at 24 months post-implant			
Predictor: receptive vocabulary at 12 months post-CI	1.04	.915	.84
Predictor: receptive vocabulary at 36 months post-CI	0.64	.917	.84
Criterion variable: receptive vocabulary at 36 months post-implant			
Predictor: receptive vocabulary at 12 months post-CI	1.33	.915	.84
Predictor: receptive vocabulary at 24 months post-CI	1.32	.917	.84

Estimated constants and linear components were used to estimate the missing values at 24 and at 36 months. There was a very high correlation of the estimated and the available scores, for the evaluations at 24 as well as those at 36 months post-implant. We concluded that this imputation method did not affect the impact of receptive vocabulary scores in further analyses and thus justified the correction for missing data.[9]

First, the development of receptive vocabulary after implantation is described by the RVAE over time. We carried out regression analyses with instructional age as the first predictor, to control for this variable. The Estimated Marginal Means were used in further analyses. Table 15 and figure 8 summarize the descriptives of receptive vocabulary. Paired sample t-tests were carried out on the pair wise combinations of means of consecutive evaluation sessions. All differences were significant (0 versus 12 months: $t(19) = -5.33$, $p = .000$; 12 versus 24 months: $t(41) = -7.36$, $p = .000$; 24 versus 36 months: $t(46) = -8.17$, $p = .000$).

9 Regression imputation is a commonly used imputation technique. In statistics, imputation is the substitution of some value for a missing data point. Once all missing values have been imputed, the dataset can be analysed using standard techniques for complete datasets. The analysis should ideally take into account that there is a greater degree of uncertainty that if the imputed values had actually been observed, however, and this generally requires some modification of the standard complete-data analysis methods.

TABLE 15

Number, estimated marginal mean receptive vocabulary age equivalent (controlled for instructional age), observed mean scores and SD, pre-implant and at 12, 24 and 36 months post-implant

	N	Estimated mean	Observed mean	*SD*
pre-implant	24	38.69	40.71	19.99
12 months	42	41.54	39.93	20.88
24 months	50	50.37	49.49	22.09
36 months	50	64.68	63.40	29.82

These results show that after implantation there was an increase of receptive vocabulary at the consecutive yearly evaluations that continued at least until 36 months post-implant. This is visible in Figure 8.

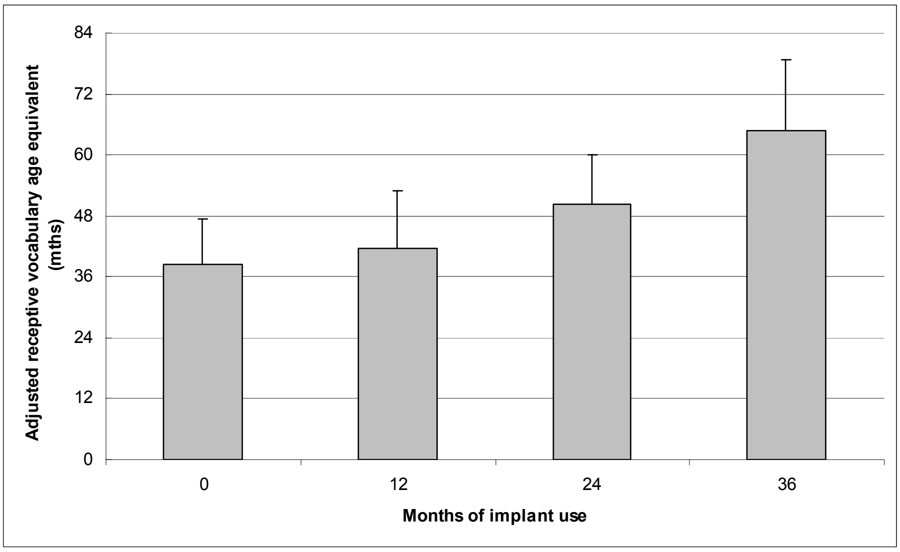

FIGURE 8 *Mean receptive vocabulary age equivalent, pre-implant (0) and at 12, 24 and 36 months post-implant*

We computed the ratio of the receptive vocabulary development (the increase of receptive vocabulary age equivalents at two consecutive evaluations divided by the time interval between the two evaluations) was calculated for the period of normal hearing, the period of deafness (hearing aid use) and the post-implant period (implant use). The ratio of language development of children with normal hearing is 1 (12 months of language development in 12 months of time). Pre-implant results could be computed only for the 24 children that were able to perform the pre-implant test the. These were the children in the group that had the best spoken language implant. The average onset of deafness of these children was 22 months (*SD* = 28), the average age at implantation was 86 months (*SD* = 20). These averages are both slightly higher than the averages for the total group (see Par. 1.2), the variability is very large however. The ratio during the period of hearing aid use was 0.63. In the first year after implantation the ratio was 0.24, in the second year 0.76 and in the third year 1.19. We found that receptive vocabulary increased and that after two years post-implant became above the level of normal hearing children! For the subgroup of children that became deaf pre-lingually (average age at onset of deafness = 10, *SD* = 15, average age at implantation = 83, *SD* = 22) the ratio before implantation was .43, in the first year post implant the ratio became .73, in the second year .86, in the third year 1.8.

Next we carried out linear regression analyses to explore the associations of reading comprehension and visual word recognition with receptive vocabulary age equivalent. In both analyses the first predictor was instructional age and in a second stage the factors receptive vocabulary at the four evaluation times were analysed stepwise. We found RVAE at 36 months post-implant to be the strongest predictor. After variance due to instructional age was removed, RVAE 36 (Beta = .49, t = 3.41, p = .003) accounted for 29% of the variance in reading comprehension. Irrespective of the association of reading comprehension with RVAE there was no association of visual word recognition with RVAE. In the Discussion (Par. 3.6) we will discuss this in more detail.

We conclude that receptive vocabulary age equivalent does increase as a consequence of implantation, and at 36 months after implantation receptive vocabulary explains a substantial part of the reading comprehension scores.

Morpho-syntactic competence

The Schriftelijke Taaltest voor Doven (STADO [Written language test for deaf children], Spreekhout, Kwint & Tellegen, 1991) a written language test for deaf children and adolescents was used for assessing aspects of idiom, morphology and syntax. The test has 5 different levels of difficulty. Each level consists of tasks concerning knowledge of synonyms, word order, idiom, and prepositions & conjunctions. This written language test exists of a booklet with 80 test items consisting of written words or sentences followed by four answer alternatives. The child had to circle one of these alternatives, numbered 1 to 4. In the subtest Synonyms each item is made up of a target word and four alternatives, one of which is a synonym of the target. For example, the four alternatives in the case of ‘mother’ are: 1 woman, 2 sleep, <u>3 mama</u>, 4 muddy. The items of the subtest Word Order consist of 4 sentences of which one had the correct word order. For example: 1 Anne my sister is. 2 Anne sister my is. <u>3 Anne is my sister.</u> 4 My Anne sister is. The items of the subtest Idiom consists of sentences in which one word is missing. One of the alternative words has to be chosen. For example:_____ the light on: 1 Press, <u>2 Switch,</u> 3 push, 4 Do. The subtest Prepositions and Conjunctions consists also of sentences in which one word is missing. Out of the four alternatives one has to be chosen. For example: The book lies _____the table:1 with, <u>2 at</u>, 3 in, 4 of.

Comparison with the STADO norm sample of deaf children without CIs, described in the STADO manual, shows that our group of children with CIs performs on average above the mean standard score for deaf children (without CIs) of the same age. The average for the children with implants was 65.36. As a group they perform better on this test than the norm group (M = 50), with hearing aids. For the children in the ages of 7, 8, 9, 13, 14 and 16 years old differences between children with implants and without implants were significant. No significant differences were found for the ages of 10, 11 12, 15 and 17 years. For the other ages of children in our sample (16, 18, 19, 20 and 21) the numbers of children with CIs of these ages were too small for statistical testing. The mean scores per chronological age for the children with CI versus the children of the norm group are shown in Figure 9.

Next we carried out linear regression analyses to explore the associations of reading comprehension and visual word recognition with morpho-syntactic competence. In both analyses the first predictor was instructional age and in the second predictors morpho-syntactic competence (sum-scores). After variance due to Instructional age was removed, morpho-syntactic competence (Beta = .76, t = 10.76, p = .000) explained 39% of the variance in reading comprehension outcomes ($F(2,49) = 124.33$, p = .000).

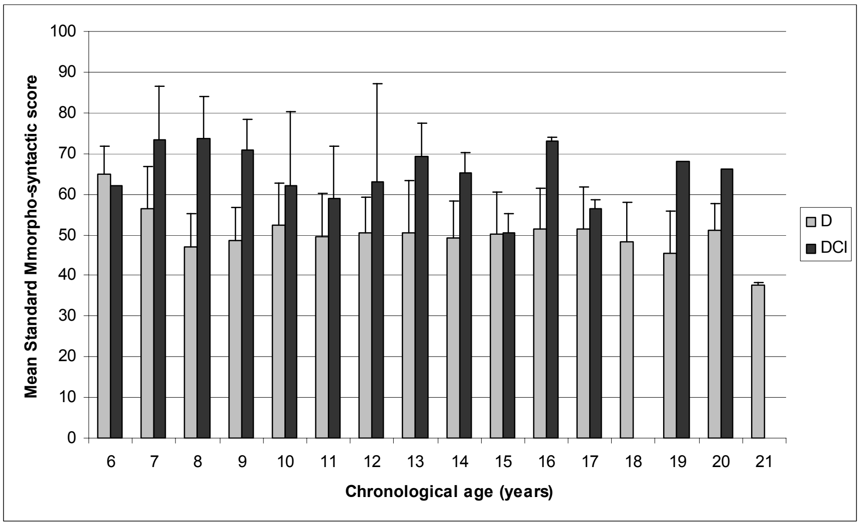

FIGURE 9 *Mean standard morpho-syntactic scores on STADO, f or the Deaf norm-group (D) and for Deaf Cochlear Implant children (DCI), per chronological age*

This strong association was reflected in the high correlation (R = .92) between morpho-syntactic competence and reading comprehension skill. We considered that this written task might measure reading comprehension skills as well. In the Discussion section this is further discussed. Again no significant association was found with visual word recognition.

Phonological skills during word reading

To investigate the access to phonology during word reading of deaf children with CIs, we developed a test procedure to determine the use of phonological information in reading. We used a lexical decision paradigm in which printed monosyllables had to be discriminated as being correct (existing) or incorrect (not existing) words. The stimulus material has been developed by Coenen (2007, pp 106-107), for a naming experiment for assessment of the use of orthographic versus phonological recoding. However, reading aloud was not regarded an appropriate task for our experiment, due to the limited intelligibility of the speech of the deaf participants. We constructed a computerised version of the task, in which manual (non-verbal) responses had to be given. The stimuli (written letter strings) were presented on the computer screen. Responses were given by pressing the ‘correct’ or ‘not correct’ button on a separate button box. No time-limits were set. Stimuli existed of one of four word types: real words, homophones, non-homophonic pseudo words and pseudo-homophones. The latter three word types were not-existing words. For example in Dutch: an existing word is /rug/ [back], the homophone was /ruch/, the pseudo word of the word was /rig/ and the pseudo word of the homophone was /rich/. The existing words were Dutch CVC's. The homophones were constructed by exchanging the similarly sounding final consonants /ch/ and /g/, and /t/ and /d/, or the identical sounding diphthongs in CVC construction, /ei/ and /ij/, and /ou/ and /au/. The non-homophonic pseudo words were constructed by changing the vowel of the real word by another vowel, in a manner that it did was not spelled like a real word and did not sound like the real word.

If reading a word involves deriving its phonological code, a homophone will 'sound' like a real word. Finding an 'existing' phonological code will hinder the accurate identification of the homophone an 'incorrect' item (a non-existing word). When phonological processes are involved in word reading, latencies for judging a homophone to be not correct, are therefore expected to be longer than for pseudo words (for example to reject /ruch/ should take longer than /rich/ and /rig/). When there is a (negative) difference between the latencies of correct responses for the homophones and pseudo-words this is regarded as evidence for the involvement of a phonological process in word reading.
Individual median latencies were calculated for the four word categories. Distributions of median latencies were normalized using a logarithmic transformation. Mean median latency for judging the homophones was 1376 milliseconds (SD = 950). For the pseudo words of the homophones these values were 1315 ms (SD = 997). The difference between these two mean median latencies was substantial, and in accordance with our speculations, 61 ms (SD = 261 ms). Figure 10 shows the scatter diagram of the latencies of homophones and pseudo words of the homophone.

This difference between the mean median latencies of homophones and pseudo words (paired sample t-test) was significant. ($t(49) = 3.49$, p =.001). These results showed longer latencies for judging homophones as being incorrect, which would point to automatic phonological processing. This means that the children with CIs that participated in our study appear to have access to phonology and to generate internal speech during reading!

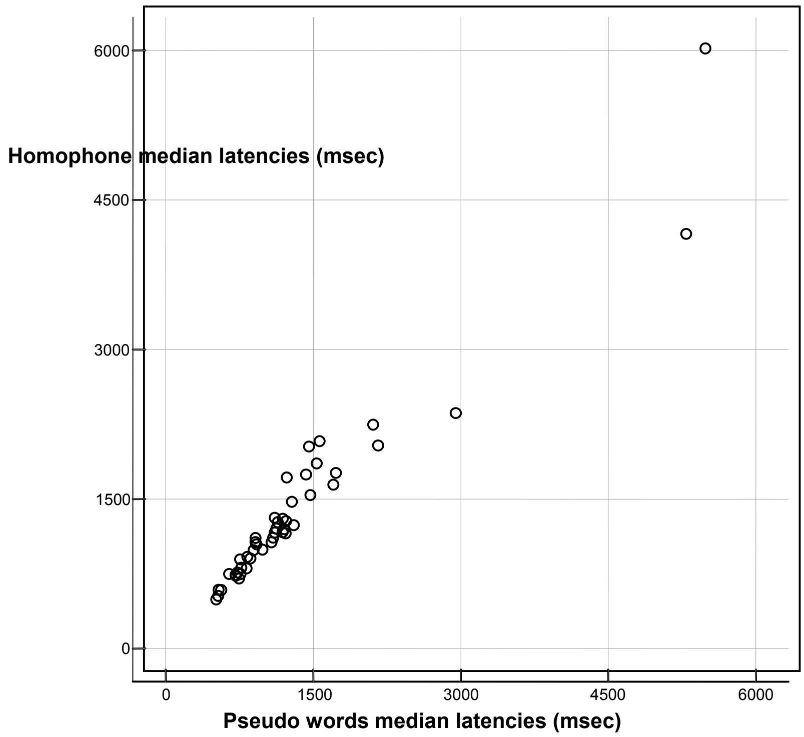

FIGURE 10 *Scatter diagram of median latencies of homophones and pseudo homophones (msec)*

We carried out linear regression analysis to explore the regression of the difference between the latencies (the sensitivity for the phonological structure of words) on their reading skills. We found no association of reading comprehension with the differences between latencies and we found no association of visual word recognition with the differences.

These findings show that deaf children with CIs have access to phonological information and use it during word reading. Nevertheless, there was no relation with the quality of their reading comprehension or visual word recognition skills.

3.4.2 Underlying factors in language outcomes

We carried out a principal axis factor analyses of the scores on the three language components to investigate whether we could identify a common factor for the use in further analyses. We found, as expected, one factor with an Eigenvalue higher than 1. The two language measures (receptive vocabulary and morpho syntax) showed high factor loadings but the measure of phonological skill showed only limited loading. We did not use this factor, because as shown above, there was a very strong association between the reading comprehension scores and the STADO scores, indicating that both expressed the same skills.

3.4.3 Audiological and environmental variables

Because no reliable common factor could be extracted from the language assessment scores, we used the receptive vocabulary age equivalents to evaluate the effect of audiological and environmental factors on (the development of) language comprehension.

The effect of audiological profile on receptive vocabulary

The results of the ANCOVA with audiological profile as factor, instructional age as a covariate and receptive vocabulary as dependent variable showed no significant overall F-value ($p = .15$). The audiological profile had no effect on receptive vocabulary.

The effect of educational setting on receptive vocabulary

The relation between educational setting and receptive vocabulary was also determined with ANCOVA with instructional age as the covariate. The descriptives of the three educational settings 36 months post-implant are shown in Table 16.

TABLE 16

The number of subjects, the estimated marginal mean receptive vocabulary age equivalents (controlled for instructional age) the observed mean equivalents and SD, per level of educational setting at 36 months post-implant

Educational setting 36 months post-implant	*N*	Estimated marginal Mean	Observed Mean	*SD*
Deaf education	20	49.97	48.95	18.88
Hard-of-hearing education	11	80.19	82.46	34.57
Mainstream education	16	69.62	68.38	30.12

The effect of audiological condition on post-implant receptive vocabulary was significant ($F(2,43) = 6.17$, $p = .004$). Pairwise comparisons showed that three years post-implant the children in deaf education were performing more poorly than those in education for the hard-of-hearing (mean difference = -30.22, $p = .006$) and than those in mainstream education (mean difference = -19.64, p = .030) (one-tailed test).The post-implant receptive vocabulary age equivalent of children that were in education for the hard-of-hearing or in mainstream education did not differ.The effect of pre-implant educational setting on pre-implant receptive vocabulary could not be assessed due to the limited number of children (there were only 24 observed vocabulary equivalents) that was in mainstream education (1).

The effect of auditory approach on receptive vocabulary

ANCOVA of the effect of emphasis placed on auditory approach in the home situation, with instructional age as the covariate, on receptive vocabulary age equivalent showed no effect. However, we found an effect of auditory based approach in the school situation ($F(3,43) = 5.76$, $p = .006$). Table 17 summarizes the descriptives. Pairwise comparisons showed that children who were educated in a school environment that had a predominantly auditory based approach performed better than those educated in environments with a moderate auditory based approach (mean difference = -26.87, p = .006).

TABLE 17

The number of subjects, the estimated marginal mean receptive vocabulary age equivalents (controlled for instructional age) the observed mean equivalents and SD, per level of auditory approach in the school environment

	N	Estimated Mean	Observed Mean	*SD*
Limited	3	76.41	79.33	15.98
Moderate	13	44.03	40.54	9.01
Predominantly	31	70.89	71.45	31.55

3.4.4 Conclusions

We evaluated three language components after implantation and assessed their association with reading skills. First, we studied two language comprehension components, receptive vocabulary and morpho-syntactic competence and next we investigated phonological text decoding skill.

With respect to receptive vocabulary we found that prior to implantation almost half of the children could not perform a spoken receptive vocabulary task. The ratio of language development of the children who could, was about half of that of normal hearing children. We found that receptive vocabulary increased significantly in the first three years after cochlear implantation. After two years of implant use the ratio was slightly above that of normal hearing children. The receptive vocabulary age equivalent at three years post-implant explained a large part of the variance of reading comprehension scores. Two environmental characteristics were influencing post-implant receptive vocabulary. A higher receptive vocabulary age equivalent was associated with educational settings for the hard-of-hearing or mainstream settings. Furthermore children with a larger vocabulary size tended to be in environments that place great emphasis on an auditory approach. No effect of audiological characteristics was found on receptive vocabulary.

The morpho-syntactic competence of the children with implants was on average better than that of peers without implants. The relation with reading comprehension was extremely strong and we conclude that the STADO should be considered to be assessing reading comprehension skills.

In addition to these two language comprehension components we investigated the phonological text decoding skill of the children with CIs. We found that they used phonological decoding during word reading. This process interfered with the identification of homophones as being spelled incorrect. This is not generally found in profoundly deaf children! We found no relation of the difference between the latencies for homophones and pseudo-words with the quality of reading skills however. These conclusions are discussed in more detail in Par. 3.6.

3.5 Associations between receptive vocabulary and speech perception

In Par. 3.3 we concluded that the improvement of reading comprehension after cochlear implantation was not associated directly with better auditory speech perception skills. This is in agreement with our expectation that the development of auditory speech perception would influence reading comprehension via language components. In Par. 2.3.2 we found that visual word recognition did not explain the better reading comprehension of deaf children with implants. Therefore we therefore hypothesized that the positive effect of cochlear implantation to reading comprehension would take place primarily via growth of receptive vocabulary (Vermeulen, Van Bon, Schreuder, Knoors & Snik, 2007).

In order to explore the relation between auditory speech perception skills and receptive vocabulary we carried out linear regression analyses. We expected that the auditory skills at a certain follow-up evaluation would predict the consecutive receptive vocabulary. We analysed the association between the receptive vocabulary age equivalent at 24 and 36 months after implantation and the equivalent hearing loss at 12 and 24 months after implantation. In both analyses instructional age was the first predictor. In the first analysis EHL values at 12 and at 24 months post-implant were the second predictors (in a stepwise analysis) and receptive vocabulary at 24 months post-implant was the criterion. In the second analysis equivalent hearing loss at 12, at 24 and at 36 months were the second predictors (in a stepwise analysis) and receptive vocabulary age equivalent at 36 months post-implant was the criterion variable.

The results showed that receptive vocabulary at 24 months post-implant was best predicted by equivalent hearing loss at 12 months. Instructional age (Beta = .41, t = 3.00, p = .004) and equivalent hearing loss at 12 months (Beta = -.50, t = -4.23, p = .000) together explained 41% (adjusted R^2 = .38.6) of the variance in receptive vocabulary age equivalent at 24 months post implantation ($F(2,43)$ = 15.17, p = .000). Receptive vocabulary at 36 months was best predicted by equivalent hearing loss at 24 months. Instructional age (Beta = .43, t = 3.60 p = .001) and equivalent hearing loss at 24 months (Beta = -.44, t = -3.71, p = .001) together explained 40% (adjusted R^2 = .37) of the variance in receptive vocabulary age equivalent at 36 months post implantation ($F(2,45)$ = 14.23, p = .000).

As expected in both cases the auditory speech perception skills were found to explain a large part of the variance of the receptive vocabulary size assessed one year later. This indicates that there probably is a causal relation of the auditory speech perception skills with later receptive vocabulary. In Chapter 4 the results of these explorative analyses will be further investigated by Structural Equation Modelling.

3.6 Discussion

In the present chapter we studied the post-implant development of auditory speech perception skills and language components. Moreover, we explored the relation between post-implant auditory speech perception, language skills and reading skills. The influence of audiological and environmental variables on reading skills, auditory speech perception and language skills was also investigated.

In Par. 3.2 we studied the direct effects of audiological and environmental characteristics on reading comprehension and on visual word recognition. Exploring the effects of the 'audiological profile' we found the best level of reading comprehension in children who acquired deafness at a later age or in children with a short duration of deafness. Reading comprehension levels in congenitally deaf children with a long period of deafness were the poorest. The environmental variable educational setting also influenced reading comprehension. This result is reported in other studies as well. Geers (2003) reported a tendency for better readers to be placed in mainstream settings. She found that educational placement contributed 6% to explained variance in reading competence, when child and family characteristics was accounted for. These results are consistent with outcomes of other studies that find an oral communication mode and auditory training to be major factors in facilitating reading skill development. Moog & Geers (1999), reported 50% of 22 children implanted between the age of 1 and 7 years old, in oral education, to obtain reading quotient scores in the range of hearing children. Moreover, our findings with respect to the effect of emphasis on auditory approach showed that better readers are found in environments that use auditory approaches in the first years after cochlear implantation. In our population many children changed from educational setting after implantation, which is commonly observed. These changes are frequently considered to be a result of the influences of cochlear implantation. On the other hand, placement in hard-of-hearing and mainstream settings that place more emphasis on auditory verbal methods positively influences post-implant outcomes. Moreover, Geers (2006) argues that children with better language and reading skills are the ones that tend to be placed in mainstream education. It is important to note that the children that participated in the present study were mainly mainstreamed based on cultural or geographical factors (see Chaper 5, Discussion section).

In Par. 3.3 we investigated the development of auditory speech perception in the first three years after implantation and studied the associations of reading comprehension and visual word recognition with long-term post-implant auditory speech perception skills. Furthermore we assessed the influence of audiological and environmental variables on the auditory speech perception skills.

We found that the auditory speech perception skills of children with a cochlear improved remarkably after cochlear implantation. We attribute this improvement to the use of the cochlear implant, for most children have used a conventional hearing aid and have received auditory training for a long time before implantation. Nevertheless, no speech perception abilities had developed. The improvement we found is comparable to that reported in literature (Par. 3.1). The speech perception skills of children that use CIs were at the level of hard-of-hearing children with a hearing loss of 70 to 90 dB. The improvements commenced even in the first year after implantation and continued until at least 36 months after implantation. The entire increase was difficult to track with the open set speech perception test but the equivalent hearing loss value was very useful for this purpose because pre-implant performance could also be determined with this method. The auditory speech perception skills, at at least 36 months post-implant, showed no association with reading comprehension. This in accordance with results reported by Geers (2003), who found speech perception scores after cochlear implantation not to contribute independently to reading outcomes. The classification of audiological variables in the factor levels of the variable audiological profile proved to be an adequate indicator of post-implant auditory speech perception skill. Children with congenital deafness and a long duration of deafness indeed performed more poorly than congenitally deaf children with a shorter period of deafness. With respect to the effect of environmental variables on speech perception skills we found that children in mainstream settings had better speech perception skills than those in settings for deaf education. This is in accordance with our finding that environments that place more emphasis on an auditory approach to the children are those in which children with better speech perception skills are found. The use of speech (with or without the use of signs) is often reported as a primary rehabilitative factor in auditory perception after implantation.

In Par. 3.4 we studied three language components, receptive vocabulary, morpho-syntactic competence and phonological text decoding skill. We also investigated the associations of reading skills with these language components. Furthermore, we assessed the effect of audiological and environmental variables on the development of receptive vocabulary in the fist three years after implantation.

The results show that after cochlear implantation the size of receptive vocabulary improved significantly each year. Before implantation, with conventional hearing aids, the ratio of language development over time was slightly more than half of that of children with normal hearing. In other studies ratios of 0.5 and less are reported (Svirsky et al., 2000; Connor et al., 2006). Our calculations included the best performing children of our group however, and contained children with a high age at onset of deafness. After implantation the ratio started to increase. In the pre-lingually deaf children already after 24 months of implant experience, development of receptive vocabulary was catching up with that of hearing peers. These findings are similar to results in other studies (Svirsky et al., 2000, 2004; Vermeulen, 1999). Although, in many studies improvements are also observed in the first year of implant use, we found a slower development. Recent studies of children with implants at a younger age show a relative fast growth of receptive vocabulary that is followed by a stabilisation at a normal ratio of development. The relatively high age at implantation of our population was expected to cause the delay in the period in which improvements occurred (Kirk et al., 2002; Svirsky et al., 2004). The effect of audiological and environmental variables on receptive vocabulary was also investigated. We found no effect of audiological profile on language skills when we controlled for instructional age. Geers (2003) reported, however, that onset of deafness after birth, even within the pre-lingual periods, provides an advantage for language development. This is not clearly reflected in our data, though the lowest scores are obtained by the congenital deaf groups, there was no significant overall effect. The post-implant educational setting did influence the receptive vocabulary of children after implantation. Children in mainstream and in hard-of-hearing settings had higher receptive vocabulary age equivalents (controlled for instructional age) than those in special education for the deaf. We found that environments that placed more emphasis on an auditory approach to the children at school and at home showed a positive effect on language outcomes. With respect to the relation between reading comprehension and receptive vocabulary we found, as expected (Par. 3.1), the receptive vocabulary at 36 months after implantation to explain a large part of the variance of reading comprehension scores.

The second language comprehension component that we studied was morpho-syntactic competence. As discussed in the Par. 3.1, we expected that the use of implants would improve this competence. We were not able to evaluate the development but the average for children with implants was higher than that for a norm group of deaf children without implants. With respect to the relation with reading comprehension, we observed a very strong association between reading comprehension and morpho-syntactic competence. We, therefore, concluded that both tasks assess the same skills. Rather than to view the outcomes of the morpho-syntactic assessment as a predictor for reading comprehension we considered the STADO to be another type of reading comprehension measure.

The third language component we studied in Par. 3.4 was phonological text decoding skill, in word reading. Surprisingly, we found that the deaf children with CIs used phonological representations during word reading: their responses were blocked by phonological resemblances of homophones with existing words, showing that the children were sensitive to the phonological structure of written words. Of our group of 45 children with a cochlear implant 71% was having access to the phonological structure of words, though (showed longer latencies for judging homophones as miss-spelled, than for pseudo words. We found no associations of reading comprehension and visual word recognition with phonological text decoding skill. This absence of an association with reading comprehension may lie in the fact that once phonological skill is present, other language components become more important in determining word recognition and comprehension. As argued by Hoover and Gough, decoding is necessary but not sufficient for reading comprehension. We expect that for an association with reading skills word specific (lexical) knowledge for this group of children might play an additional role.

Remarkably, we found no associations of any of the variables studied in this chapter (audiological and environmental variables, auditory speech perception and language components), with visual word recognition. Visual word recognition was measured with a lexical decision task. The ability to decide whether a written word is written correct or not, appeared to have no relation with auditory perception, not with the receptive vocabulary and not with the phonological skill. We reported that reading comprehension of deaf children with CIs surpassed that of deaf children without CIs (Par. 2.3). In the present chapter we observed that reading comprehension of deaf children with CIs appeared to rely also on other subskills than visual word recognition alone. Neither auditory speech perception, nor receptive language skills contributed to reading comprehension via an effect on visual word recognition. This was also in accordance with our findings reported in Par. 2.1, that visual word recognition skills were associated with reading comprehension but that they could be regarded as relatively independent skills. This might explain why factors that did contribute to reading comprehension would not necessarily contribute to visual word recognition. Another reason for the absence of associations of visual word recognition with auditory speech perception, language comprehension skills and decoding skill may be the fact that the visual word recognition skills of the children with implants were comparable with those of hearing children, and the reading comprehension skills were not.

The explorations in this Chapter showed that cochlear implantation improved hearing thresholds and auditory speech perception skills of profoundly deaf children to a level that exceeds by far the level they reached with conventional hearing aids. Audiological variables affected the development of speech perception skills after cochlear implantation. A shorter duration of deafness and an older age at onset of deafness positively influenced post-implant perception skills. In environments that place emphasis on an auditory approach to the children the auditory skills tended to develop better. The enhanced speech perception skills had a statistically small contribution to reading comprehension in a direct and independent manner. Reading comprehension of profoundly deaf children was primarily predicted by spoken language skills. Importantly, the auditory speech perception skills after cochlear implantation accounted for a large part for the development of receptive vocabulary of spoken language. We expect this to be one of the reasons for the better reading comprehension skills of deaf children with CIs, compared to those without CIs. Further analyses of the interrelations between these variables are considered necessary to gain insight in the way in which enhanced auditory speech perception affects reading comprehension. In the next chapter we will investigate these relations therefore, with a special technique, Structural Equation Modelling.

Chapter 4 ● **Factors in reading comprehension**[1]

Cochlear implantation is associated with better reading comprehension in deaf children. The present study aimed to verify links in a hypothesized causal chain between the use of a cochlear implant and improved reading comprehension.

Using Structural Equation Modelling, first, a *reading comprehension model* based on the Simple View of Reading model (Hoover & Gough, 1990) was tested, that specified the contributions of decoding and language comprehension to reading comprehension. Next a *post-implant development model* was tested. This model specified the relations between the development of auditory speech perception after cochlear implantation and later development of receptive vocabulary. Finally, both models were combined to an integrated model, in which the relation between auditory speech perception and reading comprehension was tested.

The results showed that the relatively high level of reading comprehension of deaf children with cochlear implants (CIs) can for a large part be attributed to the development of receptive vocabulary that, on its turn, is associated with their improved auditory speech perception abilities. This finding indicates that the reading comprehension level of deaf children after cochlear implantation was a result of the higher accessibility of spoken language through the use of a cochlear implant.

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1 A slightly adapted version of this chapter is submitted for publication. Reference: Vermeulen, A., van Bon, W., van Leeuwe, J., Schreuder, R., Knoors, H., & Snik, A.. Language factors in reading comprehension after cochlear implantation. The Volta Review.

4.1 Introduction

Decoding print is based on the application of letter-to-sound correspondence and it is, therefore, difficult to achieve for children with limited auditory abilities. Perfetti and Sandak (2000) argued that the limited access of deaf children to spoken language lies at the root of their difficulties with reading, because reading is a speech-based system. However, more elements involved in the interdependence of spoken language and reading may influence the performance of deaf children negatively. For example, deficits in vocabulary and syntax also cause reading difficulties in deaf children (Marschark & Harris, 1996; Musselman, 2000; Paul, 2003). We expected that the use of CIs, providing auditory access to spoken language, would improve the poor reading skills of deaf children not only through better decoding but also through improved language skills. This study focused on the effect of CIs on the ultimate goal of reading, reading comprehension. In children with profound deafness who use conventional hearing aids, reading comprehension has been found to lag substantially behind that in their peers with normal hearing (e.g. Holt, 1993; Holt, Traxler & Allen, 1996; Traxler, 2000; Wauters et al., 2006).

Enhanced auditory access to speech sounds after cochlear implantation was expected to provide new opportunities to help deaf children learn to read. In the literature, first support for this was reported by Tomblin, Spencer and Gantz (2000), who found that cochlear implantation was associated with improved spoken language and reading. Further support for improvements of literacy were reported by Spencer et al. (2003), who stated that better language skills in children with CIs were related to the development of literacy. Geers (2003) reported that children with CIs acquired better reading skills than those of children without CIs and that their reading skills were associated with improved post-implant language skills. Using structural equation modelling techniques, Connor and Zwolan (2004) found that age at implantation through post-implant vocabulary had a strong effect on reading outcomes in young deaf children.

Observations of superior reading comprehension of children with CIs also were made by Vermeulen et al. (2007), who investigated the reading comprehension of 50 Dutch children and adolescents with CIs. The performance of these children was better than that of the deaf children with conventional hearing aids. Nevertheless, on average, the reading comprehension of children with CIs lagged more than 3 *SD* behind that of their peers with normal hearing.

In the study by Vermeulen et al. (2007) the influence of two components of reading comprehension, defined by the Simple View of Reading model (Hoover & Gough, 1990), decoding and (spoken) language comprehension, were analysed. In the Simple View of Reading model the notion '*Listening Comprehension'* is used. To avoid confusion with auditory speech perception skills we use (spoken) *'language comprehension'*). According to Hoover and Gough the ability to read and to understand text depends on these two equally important skills: the ability to decode the written text and the ability to comprehend the language the text is written in. Vermeulen et al. (2007) found that the decoding skill of children with CIs showed a strong correlation with reading comprehension. Although, decoding skill (in previous chapters also referred to as visual word recognition skills) of the children with was better than those of children without CIs, this did not explain their higher reading comprehension scores. This was in agreement with the results of Burden and Campbell (1994) and Merrills et al. (1994) who reported that decoding was not the only factor that determined the lower reading comprehension scores of deaf children with hearing aids. Wauters et al. (2006) found significantly lower reading comprehension scores in deaf Dutch children, without CIs, than in children with normal hearing, and also reported only minor differences in decoding between these groups. Given these findings, we hypothesize that, in accordance with the Simple View of Reading model, decoding is a necessary but not sufficient skill to comprehend written information for deaf children with CIs.

The present study aimed to further investigate he role of (spoken) language comprehension in reading comprehension, in particular that of 'vocabulary knowledge'. Vocabulary is considered to be an important spoken language comprehension factor in reading comprehension. For hearing children this has been demonstrated repeatedly. Aarnoutse and Van Leeuwe (1988) reported that vocabulary size was highly correlated with reading skills. The importance of the contribution of vocabulary to reading comprehension in deaf children has been reported also by many authors (Marschark & Harris, 1996; Paul, 1996, 2003). The size and diversity of the vocabulary of deaf children with conventional hearing aids was found to lag behind that of children with normal hearing (Paul, 1996, 2003; Knoors, 2001). Improvements in the development of vocabulary in children with CIs have been reported, however, (Connor et al., 2006; Damen, Langereis, Snik, Chute, Mylanus, 2007; Geers & Moog, 1994; Geers, Nicholas et al., 2003; Miyamoto et al. 2003; Svirsky et al., 2000; Vermeulen et al., 1999). In this chapter we showed that reading comprehension was strongly associated with enhanced post-implant receptive vocabulary. In addition, a strong association was present between auditory speech perception skills and later receptive vocabulary in the children with CIs. However, no direct relation was found between auditory speech perception and reading skills. Instead, the results indicated that reading skills were being affected by auditory speech perception through improved language comprehension skills, that is, through post-implant development of receptive vocabulary.

In the same vein, we hypothesized here that the positive effect of cochlear implantation on auditory speech perception skills would positively affect reading comprehension via improved language comprehension. Hence, we studied the association between two relations (effects), to investigate their link in a hypothesized causal chain: first, the relation between the development of post-implant auditory speech perception skills and the development of post-implant spoken language comprehension; second, the relation between post-implant spoken language comprehension and reading comprehension. Doing this analysis we also examined the role of the audiological prerequisites for the development of auditory speech perception. The analyses were carried out with the technique of Structural Equation Modelling, which involves estimating and testing assumed causal relations between variables specified in models. Par. 4.2 describes some relevant principles of Structural Equation Modelling (SEM).

To test the two main relationships and their association, two submodels are specified and tested, and next are combined to one integrated model.

In the first part of this study we test a reading comprehension submodel, in which the two components (decoding and language comprehension) in the Simple View of Reading model (Hoover & Gough, 1990) are specified. Since there is a large variability in the ages of the children, a third predictor, chronological age, was added as a control variable.

In the second submodel, an audiological history and post-implant development submodel, we studied the influence of variables that preceded or influenced the effect of the two components of the first submodel. In this submodel the hypothetical relations between audiological/aetiological child characteristics, auditory speech perception and language development after cochlear implantation were specified. The audiological variables ‘age at onset of deafness’ and ‘age at implantation’ were included because they most probably influence post-implant speech perception skills. An older age at the onset of deafness means greater maturation of the auditory system and better processing of the signals from the electrodes in the cochlea. A younger age at implantation means a shorter duration of auditory deprivation and a better the signal processing capacity by the auditory nervous system

(Sharma, Dorman & Kral, 2005). These two audiological variables also affect the pre-implant language level. An older age at the onset of deafness and a shorter duration of deafness until implantation generally provide a better basis for further language development (e.g. Geers, Nicholas et al., 2003).

Deaf children with CIs in oral/aural educational settings have been reported to develop better speech perception than those in other settings. Geers, Brenner et al. (2003) found that 21% of the variance in speech perception could be explained by the educational setting, after adjustment for the variance explained by child, family and implant variables. Geers et al. concluded that children were better able to use the information provided by the implant to understand speech when they were dependent on speech and audition for communication at school. We included the educational setting after cochlear implantation in this submodel as a factor that potentially influences auditory speech perception because we expected that improved auditory speech perception was an important factor in facilitation of reading comprehension.

Lastly, the relations that are specified in the two submodels are combined to an integrated model, in which we make a connection between the post-implant development of language components, as a consequence of auditory speech perception, and the reading comprehension.

Par. 4.3 describes the hypothesized relations between variables. Par. 4.4 presents data considerations and descriptives. In Par. 4.5 reports the estimation of the relations between variables and assessment of the goodness of fit of the (sub)model. The last Paragraph, 4.6, discusses the results.

4.2 Structural Equation Modelling (SEM)

We used Structural Equation Modelling (SEM) to estimate and test the plausibility of the models against data at hand. The relations between variables were estimated from the variances and covariances, and expressed as (standardized) coefficients that quantify the predictive value of the variable given the contributions of other predictors of the criterion variable. In SEM, fit indices are computed to express the plausibility of a model. Generally, the plausibility of a model is judged based on a combination of several indices.

We considered the Normed Chi-square (NC) index to be the most appropriate fit indicator, because our sample was small. The NC takes the degrees of freedom of the model (df_M) into account, NC = χ^2_M / df_M (Kline, 2005). NC values not higher than 3.0 are considered to indicate reasonable fit. We also used five other common measures of goodness of fit. The first one was the Model Chi-square (χ^2_M) value with its associated probability level. The higher the χ^2 value and the lower the p level are, the poorer the fit is. Next, we reported the absolute fit indexes Goodness of Fit Index (GFI) and Adjusted Goodness of Fit Index (AGFI). Values of .8 or more indicate reasonable fit. The AGFI makes downward corrections of model complexity of the GFI. We also reported the Normed Fit Index (NFI). An NFI value of .9 or higher indicates a good fit. (See Kline, 2005, for further descriptions of these measures.) Furthermore, Root Mean Square Error of Approximation (RSMEA) that adjusts for model complexity favours the simpler model when two models have equal explanatory power. An RSMEA index of 0 indicates the best fit and higher values indicate worse fit; an RSMEA smaller than .05 indicates close approximate fit; values of between .05 and .08 suggest reasonable error of approximation; values higher than .08 suggest poorer fit.

The AMOS software programme (Analysis of Moment Structures; Arbuckle, 2003) (see also Kline, 2005), was used to make model estimations and to test each model.

4.3 Specification of the relations between variables

Figure 1 gives a global depiction of the hypothesized relations between the variables. The conceptual model of relations between auditory, language and reading variables was split into two separate parts.

Audiological history post-implant development → Long term language comprehension → Reading comprehension

FIGURE 1 *Conceptual model of the relations between auditory, language and reading variables*

The first submodel covered *reading comprehension* in which relations were specified that explained the variance in reading comprehension on the basis of the components in the

Simple View of Reading; decoding and language comprehension, that were present after at least 36 months of implant use. The second submodel aimed to evaluate the influence of variables that preceded the effect of the components specified in the first submodel. It can best be regarded as the specification of *previous audiological history and post-implant development* submodel, in which we determined relations between audiological/aetiological child characteristics, auditory speech perception after implantation and language development after implantation. Then the relations specified in the first two submodels were combined to an integrated model. Below we discuss the rationale for the model specifications and present the various models. Estimations and analyses of the models are given in Par. 4.5.

Specification of the submodel on reading comprehension

Figure 2 shows the relations between the variables in the reading comprehension submodel. Below we discuss the instruments that were used for assessment.

Reading comprehension assessment took place at the child's school, supervised by the child's (peripatetic) teacher. Two measurements of reading comprehension (tests A and B) were included as dependent variables in the reading comprehension submodel. In Par. 3.3.1 we found that the reading comprehension scores on the Reading Comprehension test devised by Aarnoutse (1996) were highly associated with the scores on the STADO, a morpho-syntactic competence test at sentence level. We concluded that the STADO in fact should be considered as an assessment of reading comprehension skills and therefore, included the STADO in our analyses as a reading comprehension test (at sentence level).

- Reading comprehension test A is the Schriftelijke Taaltest voor Doven (STADO-R, [Written language test for deaf children], Spreekhout et al., 1991) a test of morpho-syntactical competence on word and sentence level. Most items of this test were written, four-choice, cloze items at sentence level. The raw scores were converted to standard scores.
- Reading comprehension test B, the Begrijpend Leestests ([Reading Comprehension tests], Aarnoutse, 1996), is a measurement of the comprehension of texts. It consists of several short texts that have to be read silently, followed by four-choice questions about the story content. The raw scores were converted into latent reading comprehension scores.

Our model specified that Reading comprehension task B required at least the same reading related skills as those that were measured with reading task A. Moreover, we expected that the comprehension of the text contents as assessed in task B, was associated with background knowledge for which 'age' was the most suitable index in our data-set.

Decoding, was assessed with two lexical decision tasks (Wauters et al., 2006). The stimuli were monosyllabic letter strings (CVC, CV or VC) that were either highly frequently occurring words or orthographically legal pseudo-words. They had to be read silently and the words had to be discriminated from the pseudo words. Raw scores were the numbers that were discriminated correct within one minute. The scores were converted to *z* scores for each test. The average of the two *z* scores per child was used in the analyses.

Receptive vocabulary, at 36 months post-implant (which for every participant was the most recent evaluation of vocabulary) was used as an index of the comprehension of spoken language. It was assessed with a standardized test, carried out by a speech therapist at the cochlear implant centre. Depending on the language level of the children a Dutch version of the Reynell Developmental Language Scales (Reynell, 1977) or the Taaltests voor Kinderen (Language Tests for Children, van Bon, 1982) was used. The two tests have standardized testing procedures and norms for hearing children. Receptive vocabulary age equivalent scores (i.e. language age in months) were used in the analyses. The control variable *age* was expressed by the chronological age (in months) of the children, at the time when administration of the reading comprehension tests in 2002 took place.

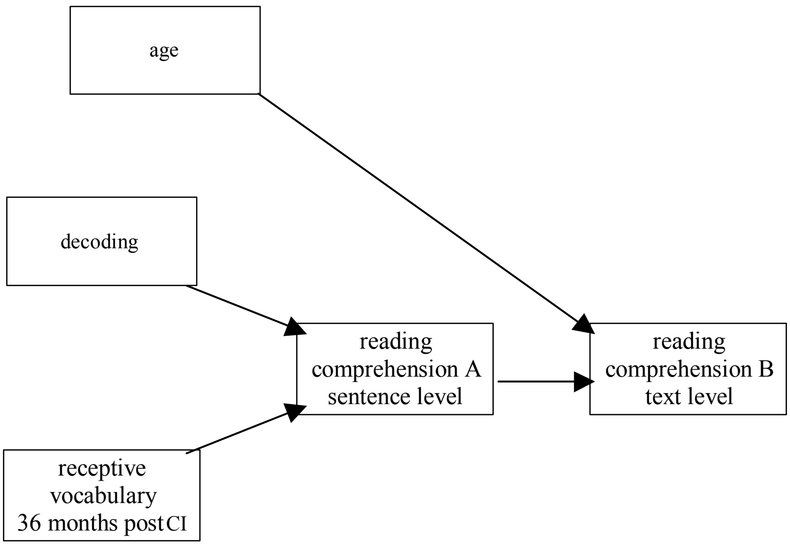


FIGURE 2 *Submodel on reading comprehension*

Specification of the submodel on audiological history and other variables in the post-implant development

In the second submodel, we specified the relations between the audiological history of the children with CIs, their post-implant auditory speech perception development and post-implant receptive vocabulary development. Explorative analyses in Par. 3.3 and 3.4 showed that these relations were important for the effect of cochlear implantation on reading comprehension. The next variable to be added was educational setting (until 2 years after cochlear implantation) to estimate its contribution to the development of auditory perception. Figure 3 summarizes the relations studied in the second submodel.

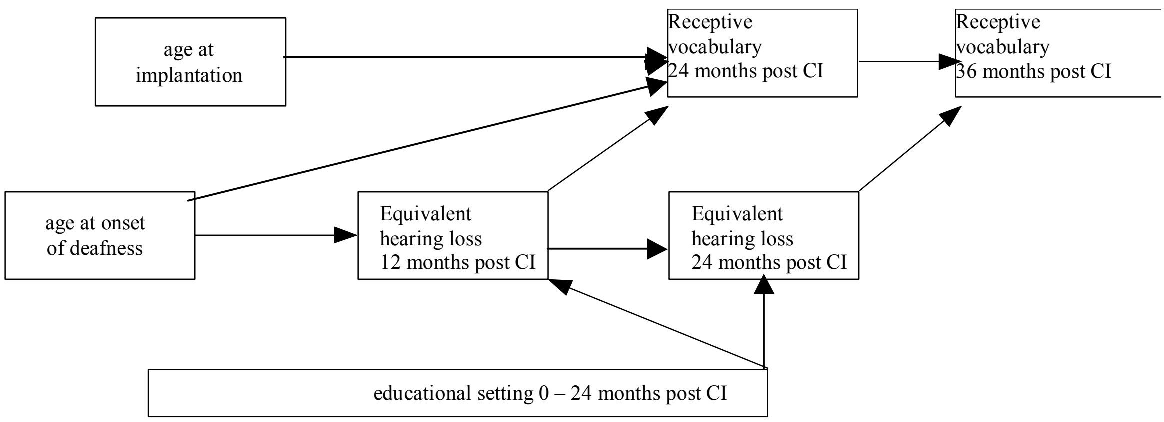


FIGURE 3 *Submodel on audiological history and post-implant development*

The *audiological history* was expressed by *age at onset of deafness* and the *age at implantation*. These variables were quantified in months (see the description of the participants in Par. 1.2 and Table 1). Post-implant a*uditory speech perception skills* were expressed by means of the *equivalent hearing loss* value (EHL), in dB HL (Snik, Vermeulen, Brokx et al., 1997). The EHL was based on reference data on deaf and hard-of-hearing children that used conventional hearing aids. The EHL expressed the hearing loss of the reference children that acquire the same score as the tested child, on a set of speech perception tests. These tests include a Dutch version of the Early Speech Perception Tests of Moog and Geers (1990), closed set word and spondee identification tests and an open set monosyllable recognition test. The equivalent hearing loss scale ranges from 130 dB HL (total hearing loss,

no auditory speech perception) to 70 dB HL (severe hearing loss, speech perception level of hard-of-hearing children).
Post-implant *receptive vocabulary* was assessed with the Reynell or TvK test. We included the 24 and 36 months post-implant vocabulary age equivalent scores in our analyses. As mentioned in the Introduction section previous analyses have shown that in our group of implant users the strongest associations were found between auditory speech perception and vocabulary scores one year later during follow-up (Par. 3.5). Therefore, we included the equivalent hearing loss values at 12 and 24 months post-implant and the receptive vocabulary age equivalent scores, one year later, at 24 and 36 months post-implant.
The *educational setting* in the first two years after cochlear implantation was a dichotomous variable: 1 for a special educational setting (a school for the deaf or a school for the hard-of-hearing), 2 for a mainstream setting (without an SLN interpreter). The order of the factor level values reflects the amount of speech (without sign support) that the children were exposed to.

Specification of the relations between auditory speech perception and reading comprehension: an integrated model.
In the integrated model we combined the two submodels (Figures 2 and 3), in order to make a connection between the enhanced receptive vocabulary as a consequence of auditory speech perception and the relatively high level of reading comprehension that received contributions from decoding and language comprehension. The connection between the two submodels was through receptive vocabulary at 36 months post-implant.

4.4 Data considerations and descriptives

Data considerations
A total of 11 variables were included in the analyses. Table 1 shows some relevant descriptives. The age at onset of deafness had the most extreme deviation from normality. This was due to the fact that for 25 of the children (50%) in this study the age at onset of deafness was zero months. Age at onset of deafness is an exogenous variable and normality, therefore, was no prerequisite. Of a total of 550 observations (11 variables * 50 cases), only 13 (2.4%) were missing. For 82% of the children the full dataset was available.

Little's Missing Completely At Random test (MCAR) showed that the missing values were randomly distributed (χ^2 (28) = 34.18, (p = .195)) and therefore they could be estimated by the EM algorithm in SPSS.

TABLE 1

Descriptives of the variables

Variable / measure	Type of units	*N*	*M*	*SD*	Min	Max
Age at onset of deafness*	Months	50	13	19	0	87
Age at implantation	Months	50	74	28	27	146
Chronological age in 2002	Months	50	153	43	87	271
EHL 12 months post-implant	dB HL	49	97.98	17.86	70	130
EHL 24 months post-implant	dB HL	49	85.55	13.32	70	120
Receptive vocabulary age equivalent 24 months post ci	Months	47	49.49	22.09	22	101
Receptive vocabulary age equivalent 36 months post ci	Months	47	63.40	29.82	25	120
Reading comprehension A	Raw score	50	57.52	14.08	21	80
Decoding	mean *z* score	45	.01	.97	-1.53	2.87
Reading comprehension B	Latent score	50	26.17	5.37	15	34
Educational setting	Ordinal value	50				

* Two children with progressive hearing loss were excluded from these computations, because the exact date of onset of profound deafness was unknown. The diagnosis of severe hearing loss had been confirmed before the age of six years.

Descriptives

Post-implant development of auditory perception and receptive vocabulary

Table 2 shows the mean equivalent hearing loss values (EHL) (Par. 3.2). Pre-implant values showed that the children on average had profound hearing loss and were unable to identify any speech presented by audition only. Paired sample t-test showed that the differences between the means for two subsequent follow-up evaluations were significant (0 versus 12 months: $t(48) = 8.85$, $p \leq .001$; 12 versus 24 months: $t(48) = 7.27$, $p \leq .001$; 24 versus 36 months: $t(48) = 3.40$, $p \leq .01$). We conclude that at least until 36 months after cochlear implantation, the EHL values of the children improved (that is, diminished) every year. The

EHL at 36 months post-implants is a hearing level similar to that of children with severe hearing loss (instead of profound deafness). Table 2 also shows the receptive vocabulary development (Par. 3.3). Pre implantation only 24 of the children had a language level that enabled them to do the receptive vocabulary test. We computed the language ratio (the increase in language age divided by the increase in chronological age in a time interval) for intervals before and after implantation.

TABLE 2

Mean (and SD) equivalent hearing loss values (in dB HL) and receptive vocabulary age equivalents, pre-implant and at 12, 24 and 36 months post-implant

	Equivalent hearing loss value			Receptive vocabulary age equivalent		
Follow-up	*N*	*M*	*(SD)*	*N*	*Mean*	*(SD)*
Pre-implant	50	121	(5.54)	24	38.69	(19.99)
12 months post CI	49	98	(17.80)	42	41.54	(20.88)
24 months post CI	49	86	(13.30)	50	50.37	(22.09)
36 months post CI	49	82	(12.61)	50	64.68	(29.82)

The pre-implant language development ratio was .63 for the prelingually deaf children that performed the test. This limited ratio had resulted in a large language delay. In the third year post-implant the ratio increased to 1.19. (For the subgroup of children that became deaf pre-lingually (average age at onset of deafness = 10, *SD* = 15, average age at implantation = 83, *SD* = 22) the ratio before implantation was .43, in the first year post implant the ratio became .73, in the second year .86, in the third year 1.8). Consequently, mean receptive vocabulary age equivalents improved after implantation. All of the differences between consecutive mean vocabulary age equivalents in follow-up (that were adjusted for instructional age) were significant (0 versus 12 months: $t(19) = -5.33$ $p \leq .001$; 12 versus 24 months: $t(41) = -7.36$, $p \leq .001$; 24 versus 36 months: $t(46) = -8.17$, $p \leq .001$). These results showed that there was an increase in receptive vocabulary over the subsequent yearly evaluations after implantation, which continued at least until 36 months post-implant.

Post-implant decoding skill

Table 3 shows the results of the decoding tasks, per grade cluster, for deaf children with and without CIs (Par. 3.3). In grade-clusters 7 to 9 and 10 to 12 (secondary education) the children with implants were significantly better. In the analyses we computed standard scores based on the hearing mean and standard deviation of the hearing reference group (Wauters et al., 2006). The average *z* score, over all grade levels, for the children with implants was .07 and that for the deaf children without implants was -.60.

TABLE 3

Mean decoding scores (and SD), for children with (DCI) and children without (D) CIs, per grade-cluster

Grade-clusters	DCI		D	
Grades 1, 2, 3	38.94	(20.10)	25.80	(10.89)
Grades 4, 5 ,6	40.94	(13.26)	36.46	(15.27)
Grades 7, 8, 9	61.00	(13.76)	47.10	(16.56)
Grades 10, 11, 12	72.17	(22.96)	56.81	(19.77)

Post-implant reading comprehension skills

The results for Reading Comprehension task A (morpho-syntactic competence at word and sentence level) showed that the children with CIs as a group (mean standard score = 65) performed better than the normative sample of deaf children without CIs (mean standard score = 50) (Par. 3.4).

Reading Comprehension task B (text comprehension above sentence level) showed that the reading scores of children with CIs (DCI) at all grade-clusters was better ($p \leq .05$) than that of deaf children without CIs (D) (Vermeulen et al., 2007). Table 4 shows the descriptives.

The average *z* score, over all grade levels, for deaf children with CIs hearing was -3.6. By definition 0 is the mean for hearing children, with *SD* = 1. The average *z* score for deaf children without CIs was - 7.2.

TABLE 4

Mean reading comprehension scores (and SD), task B, for children with (DCI) and children without CIs(D), per grade-cluster

Grade-clusters	DCI		D	
Grades 1, 2, 3	21.75	(4.43)	18.03	(2.44)
Grades 4, 5, 6	23.12	(3.95)	20.17	(4.30)
Grades 7, 8 ,9	28.18	(4.34)	22.70	(4.92)
Grades 10, 11, 12	30.82	(4.01)	24.59	(5.39)

Educational setting

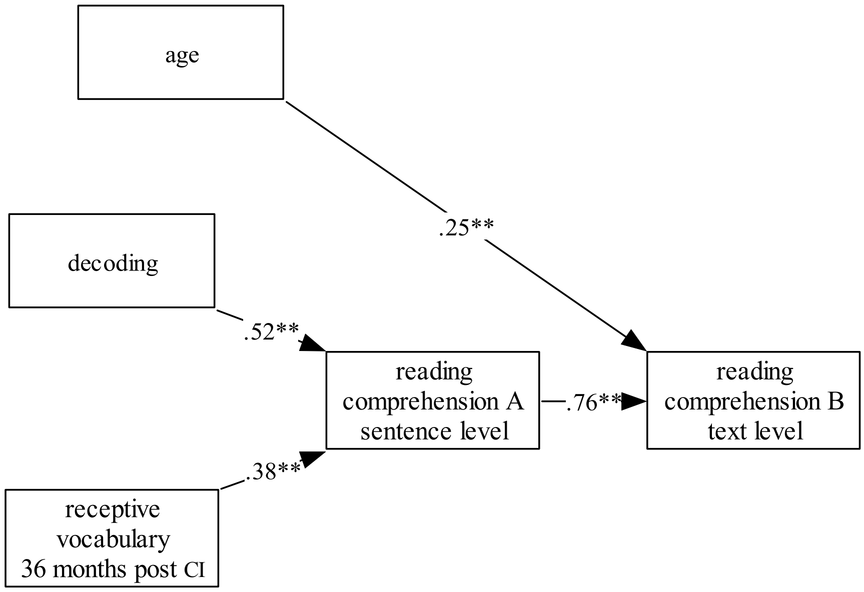
Before implantation, only 4% of the children were in mainstream education, whereas after two year of implant use this percentage had increased to 35%. In the group of children who were mainstreamed, 32% had been referred by schools for the hard-of-hearing (10% had been referred to hard-of-hearing education by a bilingual school for the deaf), 63% had been referred by an oral school for the deaf and only 5% had been referred by bi-lingual schools for the deaf. The choice to place our group of participants in mainstream education was mainly based on cultural or geographical issues. At that time chiefly the children at an oral school for the deaf or at schools for the hard-of-hearing were mainstreamed. Regardless the large shift within the first two years after implantation we conclude that the vast majority of children did stay in the same communicative environment over time. That is, children that were in mainstream settings two years after implantation were the ones that were in spoken language environments in special education before mainstreaming took place.

4.5 Model construction and assessment of the fit

In this section the (sub)models that were introduced were estimated and tested against the data. The figures show the models and depict the standardized regression coefficients of the relations between variables. Furthermore, we report the fit indexes of the (sub)models.

The submodel on reading comprehension

As shown in Figure 4, reading comprehension was strongly associated with the components in the Simple View of Reading (Hoover & Gough, 1990), decoding and receptive vocabulary.



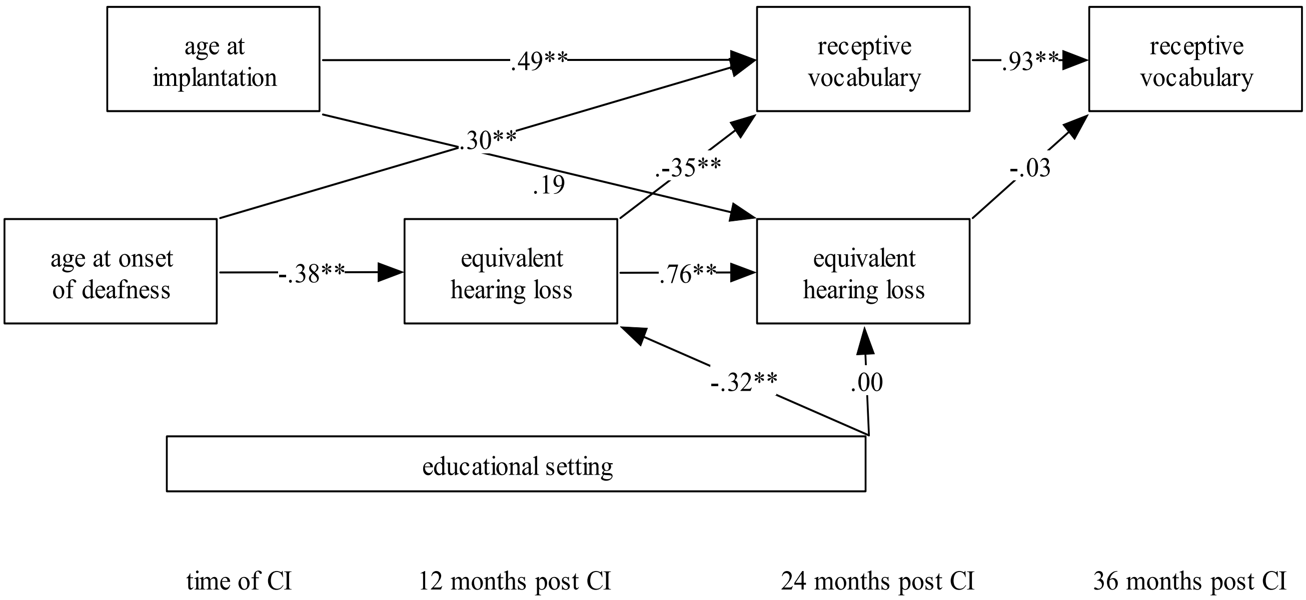
* p≤.01, ** P≤.001

FIGURE 4 *Submodel on reading comprehension*

The fit of this submodel was good: NC = .275, χ^2_3 = .826 (p = .843), GFI = .993, AGFI = .966 NFI = .996, RMSEA = .000. Decoding explained 27% (.52^2*100) and receptive vocabulary 15% (.38^2*100) of the variance in reading comprehension test A scores, respectively. Standardized coefficients showed a very strong relation between the two measurements of reading comprehension. Written morpho-syntactical competence on word and sentence level explained 58% (.76^2*100) of the variance in global text comprehension scores. Age explained an additional 7% in the comprehension scores at text level. These results demonstrated that in profoundly deaf children who use CIs, receptive vocabulary and decoding are important underlying elements in the morpho-syntactical competence of text on word and sentence level. This morpho-syntactic competence, in its turn, is highly associated with comprehension of written texts above the sentence level, to which age also contributes significantly.

The submodel on auditory history and post-implant development

Figure 5 depicts this submodel. The fit indices showed that this submodel was acceptable (NC = 2.1, χ^2_7 = 14.663 (p = .041), GFI = .919, AGFI = .674, NFI = .944, RMSEA = .149). The relations involving equivalent hearing loss values could have had negative coefficients, because lower (equivalent) hearing loss in dB reflected better hearing and thus better speech perception capacities than those in children with higher EHL values. We added age at implantation as a predictor of equivalent hearing loss at 24 months post-implant to the submodel during the analysis, because the modification indices showed that the fit would be improved by it and because this relation was not implausible.



* p≤.01, ** P≤.001

FIGURE 5 *Submodel on auditory history and post-implant development*

The high (negative) coefficient of the path between educational setting and equivalent hearing loss at 12 month post-implant showed that the auditory speech perception was better in the children in mainstream schools than in the children receiving special education: the equivalent hearing loss value was lower. Ten percent of the variance in speech perception scores was explained by this variable ($.30^2$). However, we were unable to demonstrate a significant effect of educational setting on the auditory speech perception after 24 months of implant use. This was a consequence of the large proportions of the variance in equivalent hearing loss values at 24 months that were explained by the previous equivalent hearing loss values after 12 months of implant use ($.76^2$), and because of the variance in these values that was explained by age at implantation. Fourteen percent of the variance in auditory speech perception skills at 12 months post-implant was explained by the age at onset of deafness

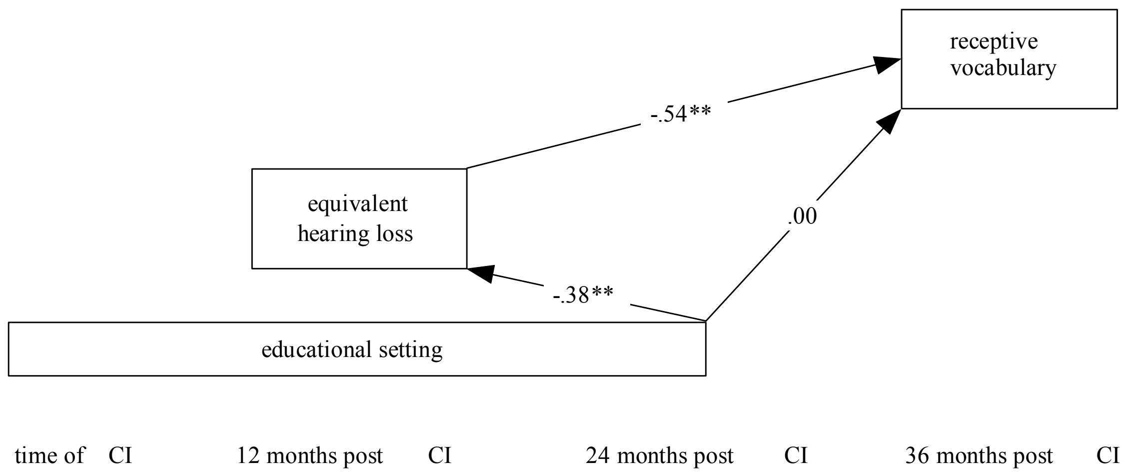
($-.38^2$). Evidently, the longer the period of hearing prior to implantation has been, the better the hearing capacities at 12 months post-implant are. The age at onset of deafness was also associated with the receptive vocabulary at 24 months post-implant. A longer period of normal hearing, prior to deafness, implies a larger post-implant receptive vocabulary.

The second independent variable in the submodel was age at implantation. It explained a larger part of the variance in receptive vocabulary at 24 months post-implant ($.49^2$) than age at onset of deafness, however. The age of implantation included two different hearing capacity conditions. First, the duration of normal hearing and second the period of auditory deprivation (with hearing aid use). The mean duration of normal hearing was 16 months and the mean duration of deafness was 58 months, a much longer period of time.

As reported earlier (Par. 3.5), the equivalent hearing loss at 12 months post-implant was associated with receptive vocabulary assessed one year later, at 24 months post-implant. The second submodel confirmed these findings: better hearing capacities one year post-implant (reflected by a lower equivalent hearing loss value at 24 months post) led to higher vocabulary age equivalent scores two years after implantation. There was no significant relation between equivalent hearing loss at 24 months post CI and receptive vocabulary 36 months post CI because most of the variance in the receptive vocabulary 36 months post CI scores was explained by receptive vocabulary 24 months post CI. The relations between the consecutive yearly auditory speech perception scores (equivalent hearing loss from 12 months post CI to that 24 months post CI) and receptive vocabulary scores (from 24 months post to 36 months post) had high coefficients, as was expected with these autoregressive relations.

This submodel demonstrated that the development of receptive vocabulary after implantation was positively influenced by the quality of post-implant auditory speech perception and that the latter developed best in mainstream settings, as expected.

An additional analysis was carried out to assess whether the educational setting had a direct effect on receptive vocabulary, besides making an indirect contribution due to better auditory input. In a new model two relations were specified between educational setting and receptive vocabulary at 36 months post-implant: a direct relation and an indirect relation. The number of degrees of freedom in this case was zero, which allowed no computation of the model fit. Figure 6 shows this model.



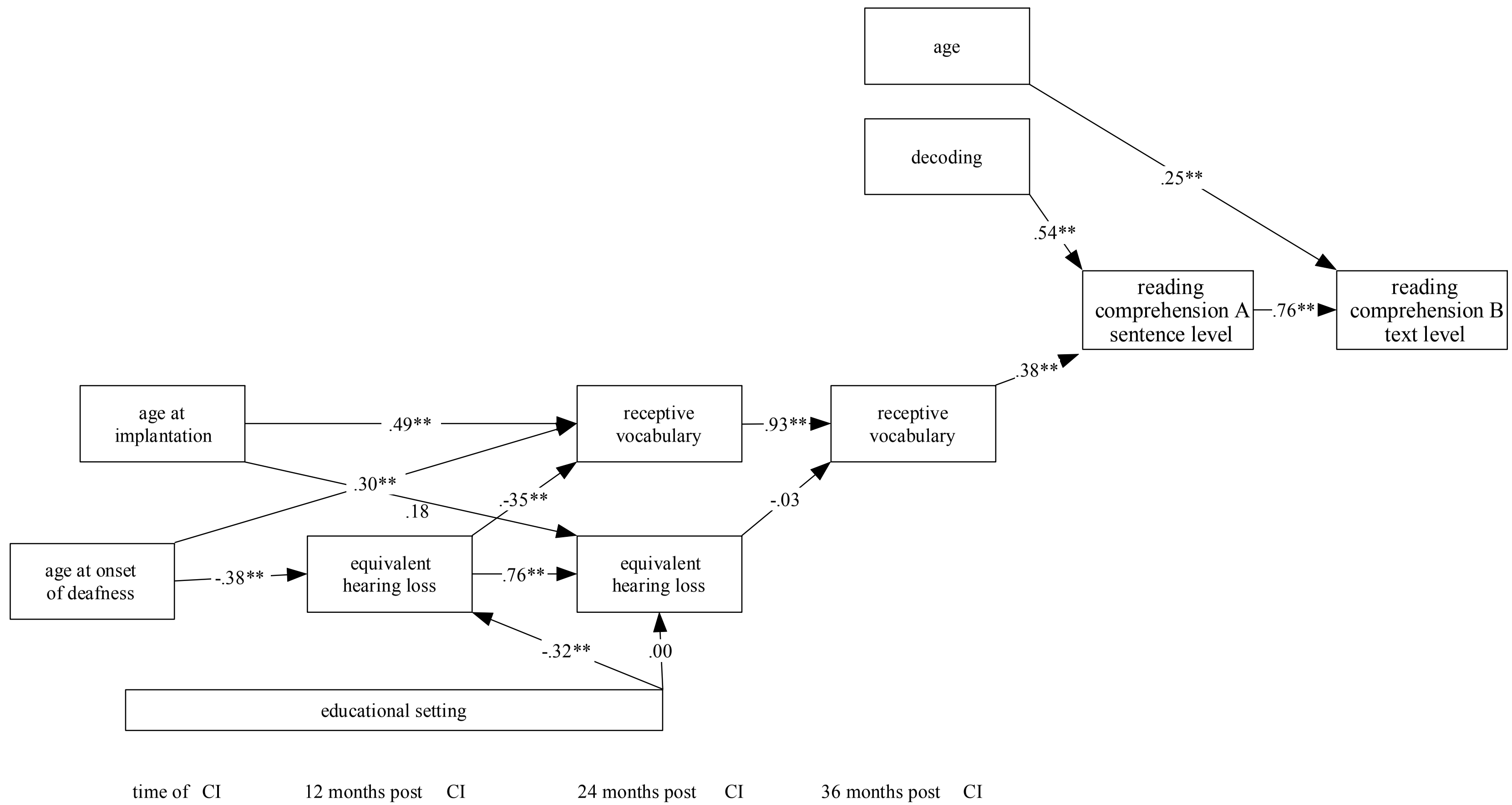
* p≤.01, ** P≤.001

FIGURE 6 *Effects of educational setting on receptive vocabulary*

Educational setting was not found to have any direct effect on receptive vocabulary. We therefore concluded that mainstreaming itself did not have any direct effect on receptive vocabulary. However, improved vocabulary after implantation was associated with better auditory speech perception, which in turn was associated with mainstream education. This meant that an indirect relation was present. Effects of educational setting on language development have been reported in the literature (see for an overview Geers 2003, 2006), but no conclusions can be drawn about a direct influence or an indirect influence.

Combination of the auditory history and post-implant development submodel and the reading comprehension submodel to an integrated model

The two submodels were combined to a single integrated model. This model (Figure 7) aimed to estimate the relations between post-implant auditory speech perception and reading comprehension. Path coefficients in this integrated model were of similar size to those in the original submodels, which indicates that the submodels could be considered stable. This model had a moderate fit (NC = 2.1, χ^2_{30} = 63.994 (p = .000), GFI = .826, AGFI = .618, NFI = .879, RMSEA = .152). The fit of the combined model was poorer than the fit of each of the two smaller models, because the integrated model was more complex.

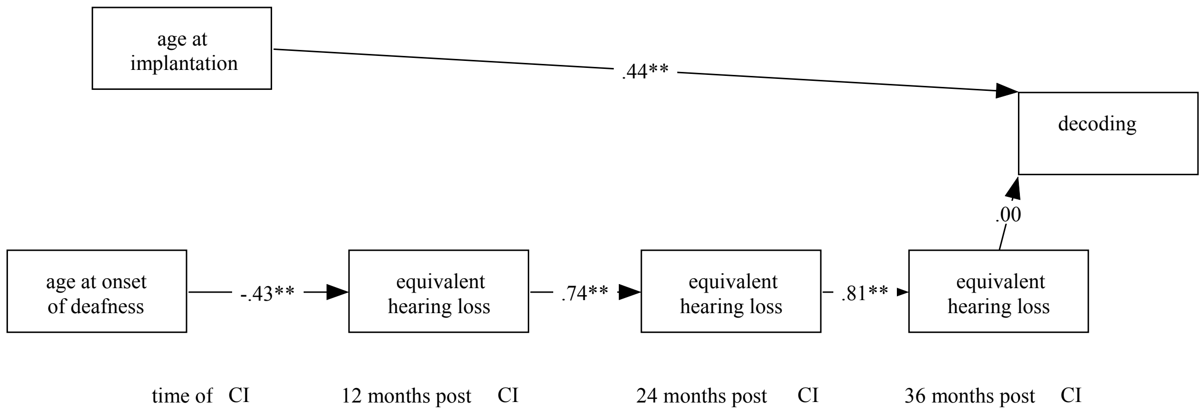


** p≤.01,** P≤.001*

FIGURE 7 *Integrated model on the relations between auditory speech perception and reading comprehension*

We concluded from this model that the children who had relatively good auditory speech perception skills after cochlear implantation tended to be the ones who had higher levels of reading comprehension. Auditory speech perception after implantation appeared to positively influence reading comprehension via post-implant receptive vocabulary. Post-implant auditory speech perception was better in the children who were older at the onset of deafness although age at implantation did not influence auditory speech perception. Age had a separate influence on reading comprehension that was larger than that of decoding and language comprehension (the two components in the Simple View of Reading model of Hoover and Gough, 1990). That is, age does also influence these components, but above that, there was an effect of age on text comprehension. We speculate that age may be considered as an index of specific background knowledge or common knowledge.

Remarkably, we found no relation between auditory speech perception and decoding; no modification indices (for such a relation) for improved fit were suggested in the integrated model. Furthermore, no direct relation between auditory speech perception and decoding was observed with regression analysis either (see Par. 3.3). Therefore, in the present chapter, we assessed this relation again using path analysis. Decoding in submodel 1 appeared to explain a large part of the variance in reading comprehension scores, just like applied to receptive vocabulary, i.e. the second element in the Simple View of Reading model. Decoding was only assessed once, after at least 36 months of implant use. (Therefore, it could not be included in the history and development submodel.) In order to investigate the effect of audiological history and auditory speech perception on decoding in more detail, we incorporated it into a model. Figure 8 shows the relations in the decoding model. Auditory speech perception 36 months post-implant was included in this model because decoding was assessed after more than 36 months post-implant and a causal relation could therefore be presumed. This model shows that the auditory speech perception at 24 post-implant explains a large part of the variance of this skill one year later. More important, however, once again, is the absence of a relation between post-implant auditory speech perception and visual word recognition. Additional analyses did not show any direct or indirect (via auditory speech perception) effect of educational setting on decoding.



* p≤.01, ** P≤.001

FIGURE 8 *The relation between decoding and audiological /auditory factors*

4.6 Discussion

Three (sub)models were tested in which the association between reading comprehension and post-implant auditory speech perception was specified, intermediated by decoding and spoken language comprehension. These factors, decoding and language comprehension are the major components of reading comprehension according to the Simple View of Reading model (Hoover & Gough, 1990). The submodel *on reading comprehension* aimed to determine the contribution of post-implant receptive vocabulary and post-implant decoding to the comprehension of written text. These two elements indeed explained a large part of the variance in written text comprehension. In the second submodel, on *audiological history and post-implant development,* we specified the relations between post-implant auditory speech perception and post-implant receptive vocabulary. We found that improved receptive vocabulary after implantation was associated with increased auditory speech perception skills, as expected. These speech perception skills developed best in educational environments that placed emphasis on spoken language. A combination of the two submodels to an *integrated* *model*, showed that auditory speech perception had a positive effect on reading comprehension, via receptive vocabulary.

Remarkably, we did not find that auditory speech perception of children with CIs affected the decoding skill. Although this was a remarkable finding it was in accordance with a similar observation: the absence of an association between decoding and post-implant auditory speech perception skills. We did not find any indications that improved auditory speech perception in children with CIs affected their decoding skill and no modification indices for improved fit were suggested in the integrated model. The absence of such a relation might be a consequence of the relatively older age and greater decoding competence of the children in our sample. Such a relation is more likely to be present at an earlier stage in the process of learning to read.

Cochlear implantation had a major influence on reading comprehension, by providing access toe auditory speech stimuli, subsequently increasing the children's receptive vocabulary. Enhanced auditory speech perception could only be attributed to cochlear implantation. All the participants in this study were profoundly deaf and despite the long duration of conventional hearing aid use (M = 74 months, SD = 28 months), auditory speech perception had not developed prior to implantation. However, one year after implantation, these children showed significantly increased speech perception abilities. One of the main reasons for this is that children with implants have better access to spoken language, i.e. they could perceive all (including high frequency) speech sounds of spoken language. Deaf children with CIs therefore receive larger and more diverse (spoken) language input than deaf children without CIs. In addition, the perceived context is richer. Placement in mainstream settings led to more rapid increases in receptive vocabulary, probably via constant exposure to linguistic referents and extensive opportunities for incidental learning via audition. This is an important issue because, as also shown by Wauters (2005), vocabulary learning via linguistic referents was difficult for deaf children without implants. As described in the Introduction, The size and diversity of the vocabulary of deaf children with conventional hearing aids was found to lag behind that of children with normal hearing. Furthermore, difficulties in reading comprehension can stem from limited vocabulary.

In the literature, there are many reports on improvements in vocabulary after cochlear implantation (Connor et al., 2006; Damen et al., 2007; Geers & Moog, 1994; Geers et al., 2003; Miyamoto et al., 2003; Svirsky et al., 2000; Vermeulen et al. 1999) and on better reading skills of deaf children with than in deaf children without CIs (e.g. Connor & Zwolan, 2004; Geers, 2003; Spencer et al., 2003; Tomblin et al., 2000). Moreover, the relation between CIs and high levels of post-implant reading skills was put forward frequently. However, until now, no relation has been established between post-implant auditory speech perception and reading comprehension. Our structural equation modelling showed that the hypothesized causal relation between enhanced post-implant auditory speech perception skills and comprehension of written text, via improved receptive vocabulary is highly plausible. We showed that the effect of cochlear implantation on reading comprehension (reflected in the connection of the association between larger receptive vocabulary size and improved auditory speech perception and to the association between the higher level of reading comprehension skills and a larger size of receptive vocabulary) explains a large part of the variance in reading comprehension scores of profoundly deaf children with CIs.

In conclusion, we investigated the link between two effects in the hypothesized causal chain between auditory speech perception and reading comprehension. Our study showed that the relatively high level of reading comprehension of deaf children with CIs could for a large part be attributed to receptive vocabulary that in turn, depended on auditory speech perception abilities. These findings indicate that the reading comprehension of deaf children after cochlear implantation is positively influenced by the higher accessibility of spoken language through the use of a cochlear implant.

Chapter 5 • **Summary and conclusion**

It has frequently been found that profoundly deaf children with conventional hearing aids have difficulties with the comprehension of written text. Cochlear Implants (CIs) were expected to enhance the reading comprehension of these profoundly deaf children because they provide auditory access to spoken language. However, until now the association between reading comprehension and hearing abilities was not verified in cochlear implant recipients.

Overview of the study and discussion

The present study focused on the evaluation of reading comprehension in profoundly deaf children with CIs. Furthermore, our investigations aimed to determine how post-implant auditory speech perception skills influenced reading comprehension. The Simple View of Reading model (Hoover & Gough, 1990) served as a framework for our analyses. In this model, reading comprehension is defined as the product of two components: decoding and (spoken) language comprehension. Therefore, we investigated the associations between reading comprehension and decoding and associations between reading comprehension and language comprehension, in CI recipients. We hypothesized that improved auditory speech perception skills would have a positive influence on the decoding and language comprehension and result in improved reading comprehension.

Overview of the study

This thesis consists of three empirical chapters that address the above-mentioned issues. In Chapter 2, the reading comprehension and visual word recognition skills (decoding skill) of deaf children with and without CIs are compared; the findings are subsequently compared to those in children with normal hearing. The first part of Chapter 3 reports on the development of auditory speech perception skills after cochlear implantation and explores the associations with reading skills. The second part of Chapter 3 investigates the development of spoken language skills after cochlear implantation and their associations with reading skills. The relation between post-implant auditory speech perception skills and post-implant language skills is also studied, including the effects of environmental and audiological factors. To investigate the hypothesized positive effect of auditory speech perception on reading comprehension, a model of the assumed causal relations between the above-mentioned variables is constructed and evaluated in Chapter 4.

A total of 50 profoundly deaf children with CIs participated In our study. They were aged between 7 and 22 years and their duration of implant use varied between 3 and 11 years. There were 25 boys and 25 girls, who all had parents with normal hearing. The children were living in various parts of the Netherlands and were also going to schools in various parts of the country. Before implantation, 74% of the children were being educated at schools for the deaf. Data on auditory speech perception, language and reading were obtained from the profoundly deaf children with CIs and compared to data from deaf children without CIs and children with normal hearing.

The reading comprehension of children with cochlear implants

In Chapter 2, we compared the reading comprehension levels of deaf children with CIs to those of deaf children without implants and children with normal hearing. We observed that the reading comprehension skill of the profoundly deaf children with CIs was overtaking that of deaf children without CIs. Nevertheless, the scores of the deaf children with CIs were still lagging behind those of the children with normal hearing. Their performance was on average between 3 to 4 *SD* below the hearing norm. Wauters kindly permitted us to use the data on deaf children without CIs that were collected in a large scale study (Wauters et al., 2006). These deaf Dutch children without implants showed that their reading comprehension was lagging substantially behind that of children with normal hearing. This was in accordance with the findings of Traxler (2000) and Traxler and Allen (1986). We believe that the superior reading comprehension of the children with CIs was a consequence of their CI use, because no other systematic difference could be identified between the two groups of deaf children.

Associations between reading comprehension and the two components in the Simple View of Reading model

To determine whether the level of reading comprehension in the children with CIs was associated with the two components in the Simple View of Reading model, we first studied decoding (Chapter 2), followed by (spoken) language skills (Chapter 3).

Decoding skill was assessed with lexical decision tasks. The scores were compared to the reference data from deaf children without implants, collected by Wauters (Wauters et al., 2006). At secondary education level, the profoundly deaf children with CIs had better decoding skill than the deaf children without CIs. No differences in distribution were found between the profoundly deaf children with CIs and the children with normal hearing. In grades four and higher, there was a significant difference in the distribution of decoding scores between the deaf children without CIs and the children with normal hearing, in favour of the latter children. The decoding z scores in the two groups of deaf children were less deviant from those of the children with normal hearing than their reading comprehension z scores. Subsequent analyses showed that the difference in reading comprehension skills between the two groups of deaf children could not be explained by differences in decoding, despite the relatively good decoding skill of the children with CIs. Nevertheless, we found that decoding explained a large part of the variance in the reading comprehension scores of the deaf children with CIs.

Next, we studied the *receptive vocabulary* of the children with CIs, as an index for language comprehension. A substantial part of the variance of the reading comprehension scores was explained by the 36 months post-implant receptive vocabulary age.

In the profoundly deaf children with CIs as well as in the children with normal hearing, decoding in itself was not sufficient to comprehend written texts. Decoding skill is necessary, but more is needed for reading comprehension. As expected, receptive vocabulary (the language comprehension component we studied) contributed significantly and substantially to the reading comprehension of profoundly deaf children with CIs.

The relation between improved auditory speech perception and reading comprehension

To investigate the relation between improved auditory speech perception and reading comprehension, we first studied the development of auditory speech perception after implantation. It was found that after implantation, auditory speech perception skills improved to a level that far exceeded the scores of conventional hearing aid users. Before implantation, speech perception skills were at the same level as those of profoundly or totally deaf hearing aid users. After 36 months of implant use all the children were able to detect speech sounds and to recognize an average of 72% of the phonemes of spoken monosyllables by audition only. As these children had spend relatively long periods with conventional hearing aids and there had been no beneficial effect on speech perception, these improvements could be attributed solely to the use of a cochlear implant. Moreover, post-implant receptive vocabulary showed a very strong association with these improved post-implant auditory speech perception skills. The results of the analyses in Chapters 2 and 3 showed an intervening role of receptive vocabulary in the association between reading comprehension and auditory speech perception with a cochlear implant. These findings formed the starting point for the Structural Equation Modelling carried out in Chapter 4. We constructed a model that specified the assumed causal relations between auditory speech perception skills and reading comprehension skills, via receptive vocabulary. The fit indices for this model showed acceptable fit. The model was a combination of two less complex submodels: a *reading comprehension submodel* and an *auditory history and post-implant development submodel*. Associations between decoding and receptive vocabulary with reading comprehension were specified in the reading comprehension submodel in accordance with the Simple View of Reading model. In the auditory history and post-implant development submodel, the relation was determined between auditory speech perception and receptive vocabulary. A larger receptive vocabulary was associated with better auditory speech perception skills, one year earlier during follow-up.

As was demonstrated in Chapter 3 and Chapter 4, these auditory speech perception skills were influenced by audiological and aetiological child characteristics. It is known that a longer period of auditory deprivation prior to implantation has a detrimental effect on the auditory nervous system and that this leads to poorer post-implant auditory speech perception skills. The period of deafness had a more detrimental effect on the congenitally deaf children than on the children who became deafness later in life (see Par. 3.3.1). Thus, age at onset of deafness and age at implantation and their interactions influence the processing capacities of the auditory system. In our group of congenitally deaf children with a long duration of deafness, this resulted in relatively poor post-implant auditory speech perception scores. Another variable that was found to affect post-implant auditory speech perception skills was the use of spoken language in the child’s environment. The Structural Equation Modelling analyses in Chapter 4 showed that the children placed in mainstream settings within the first two years after implantation had better auditory speech perception skills at the 24 month evaluation than those who were at special schools (Par. 4.5).

Our data and model (Par. 4.5) verified a link in the causal model between improved auditory speech perception skills and the relatively high level of reading comprehension in profoundly deaf children with CIs. This relation was mediated by the post-implant improvement in receptive vocabulary. Below we discuss our findings.

Discussion

The most important finding was that the reading comprehension in profoundly deaf children with CIs was better than that in deaf children without CIs. Their performance was still poorer than that of their peers with normal hearing. Compared to the results reported in other studies, the difference we found between these groups was larger. Geers (2003) reported that the performance of 50% of a group of 181 children aged 8 to 9 years old was within the 1 *SD* range of the hearing mean, while in a study by Spencer et al. (2003), 10 out of the 16 children (63%) performed within that range. The differences between the results reported in the literature and our findings may be the result of group characteristics and/or task-related factors. Effects of group characteristics are discussed in the *Limitations of this study* section, below. Differences as a consequence of the task-related factors may have arisen because we assessed reading comprehension with a question-answering task (Aarnoutse, 1996). This test consists of short stories that have to be read in silence. After each text, the candidate answers several multiple-choice questions without any time limit. It is likely that this type of measurement requires other skills than a cloze task. Questions are a more effective means to measure a person's understanding of the main ideas of the text; whereas cloze tests only reflect local understanding, instead of overall understanding. We cannot compare the reading comprehension and decoding scores from our children to those reported by Geers (2003), because she administered a text reading task and a word identification task, but reported a *combined* standard of reading comprehension and word recognition score. Compared to the hearing norms, the word recognition of our group of deaf children with CIs was better than their reading comprehension. This better decoding may have also been present in Geers' sample, which would explain the improvements in (combined) performance found in that study.

One of our main expectations was that at least part of the better reading comprehension observed in our group of children with CIs was a result of improved decoding. The new access to speech sounds was expected to facilitate the use of letter-to-sound correspondence and the use of phonological processes in text decoding. This strategy is used effectively by hearing subjects in the process of transferring print to meaning. Even in hearing aid users with severe hearing loss, better perception skills were found to be associated with the use of phonological processes and superior reading skills (Leybaert, 1993; Perfetti & Sandak, 2000). As was reported in Par. 3.4.1 the children with CIs had access to phonology during a word decoding (lexical decision) task. The participant had to judge whether written words, real words, homophones (phonological existing non-words) and pseudo words (non-homophones) were real/existing words. Surprisingly, we found that the recognition latencies of the homophones were longer, which indicated that the children were sensitive to the phonological structure of words. Contrary to our expectations, we did not find any association between visual word recognition skills and phonological skill in text decoding. Although this was a remarkable finding it was in accordance with a similar observation: the absence of an association between decoding and post-implant auditory speech perception. The absence of such a relation might be a consequence of the relatively older age and greater decoding competence of the children in our sample. Such a relation is more likely to be present at an earlier stage in the process of learning to read. The decoding skills (visual word recognition) of the children with CIs were within the 95% confidence interval of those of children with normal hearing. At secondary education level, the scores were better than those of deaf children without CIs. Relatively good visual word recognition skills in deaf children with conventional hearing aids have been reported frequently (e.g. Burden & Campbell, 1994; Beech & Harris, 1997). However, the decoding competence of the two groups of deaf children could not explain the better reading comprehension of the children with CIs, compared to the deaf children without CIs. This finding with respect to children without CIs was also reported by and by Wauters et al. (2006) and by Merrills et al. (1994). They found that poor visual word recognition skills only explained part of the reading difficulties in deaf children without CIs. Other explanatory factors were discussed by Marschark and Harris (1996) and by Musselman (2000). These authors argued that apart from decoding skill, vocabulary and syntax might also account for reading comprehension difficulties in deaf children. According to the Simple View of Reading model, decoding is necessary, but not sufficient to comprehend written text. Language comprehension is also an important contributor. We investigated two language comprehension components: receptive vocabulary and morpho-syntactic competence.

Thus, the second expectation was that language comprehension would explain a large part of the variance in reading comprehension scores. In our data the most important language comprehension component was post-implant receptive vocabulary. Increases in receptive vocabulary after cochlear implantation were also observed in other studies (e.g. Svirsky et al., 2002; Tomblin et al., 1999; Vermeulen et al., 1999). Furthermore, we found a strong association between post-implant auditory speech perception skills and later receptive vocabulary. We were unable tot determine the mechanism of this receptive vocabulary development on the basis of our data. However, it is likely that the auditory access to spoken language enabled the deaf children with CIs to learn word meanings during explicit formal instruction. Most of the children with implants were receiving mainstream education within two years of implantation, i.e. spoken language instruction. The mean standard score for morpho-syntactic competence (the other language component we studied) was higher in the deaf children with CIs than without. However, the test we used most probably involves reading comprehension, which complicates the interpretation of the large percentage of variance in reading comprehension scores that was explained by morpho-syntactic competence. Several authors reported improved morphological skills after implantation (Spencer et al., 1998; Svirsky et al., 2002; Szagun, 2004). Furthermore, children with CIs were found to have improved narrative skills (Nikolopoulos et al., 2004) and these skills had predictive value for reading comprehension (Crosson & Geers, 2001). Therefore, CIs are likely to have had a positive effect on morpho-syntactic competence and reading comprehension.

The two components, decoding and language comprehension, (and their interaction) in the Simple View of Reading model explained 59% of the variance of reading comprehension scores. Decoding explained the largest part, 48% (p = .000), while receptive vocabulary explained the other 11% (p = .005). The total percentage of explained variance was within the range of that found in general (e.g. Gough et al., 1996). Only receptive vocabulary was included in our analysis, but if other language skills had also been included, the explained variance in the language component would possibly have been higher. An argument in support of this expectation is that age was still a significant factor in reading comprehension in the SEM analyses in chapter after the effects of language components and decoding had been accounted for. Thus, age related factors, such as background knowledge and overall language knowledge, are important factors in reading comprehension in deaf children with implants. These findings indicate that the Simple View of Reading model can be applied to explain reading comprehension in deaf children with CIs.

Access to spoken language after implantation, was an important factor in the development of auditory speech perception and subsequently in the language and reading outcomes. Geers argued (2006) that children with better language and reading skills are more likely to be mainstreamed; thus the better achievements of the children in mainstream education are biased. However, in our group of children this was not the case. Before implantation, only 4% of the children were in mainstream education, whereas after two year of implant use this percentage had increased to 35%. In the group of children who were mainstreamed, 32% had been referred by schools for the hard-of-hearing (10% had been referred to hard-of-hearing education by a bilingual school for the deaf), 63% had been referred by an oral school for the deaf and only 5% had been referred by bi-lingual schools for the deaf. The choice to place children of this study group in mainstream education was mainly based on cultural or geographical issues. At that time chiefly the children at an oral school for the deaf or at schools for the hard-of-hearing were mainstreamed.

Limitations of the study

A first limitation of this study is that the results cannot be generalized to present and future paediatric implant candidates. Although the level of reading comprehension in the children with CIs was better than that in the deaf children without implants, the results were poorer than those reported in other studies. This was mainly due to the unfavourable audiological characteristics of our participants. They all had received an implant at the University Medical Centre St Radboud, Nijmegen, the Netherlands, between 1990 and 1999. The *clinical* criteria for implantation applied then, differed from the ones used later on. As a consequence of including children who received an implant in the early 1990s, the children in our group had profound hearing loss (instead of severe hearing loss) and the duration of deafness until implantation was long, especially in the congenitally deaf children. Furthermore a number of children were using devices with the less sophisticated M-Peak coding strategy (Geers, 2003).

These factors are known to provide less optimal conditions for the development of post-implant auditory speech perception abilities. On the basis of the substantially lower age at implantation applied nowadays and the use of more advanced coding strategies, we expect that far greater improvements will be seen in the reading comprehension of deaf children with CIs than those observed in the present study, due to even better access to speech signals.

A second limitation of this study is that we could not draw any conclusions about the influence of the use of Sign Language on reading skills. We found that the comprehension of spoken language was positively associated with reading skills. Most of the children in our group of implant users used spoken or sign supported Dutch. The level of Sign Language competence of children with CIs might also be associated with reading skills. There is evidence that early implantation in children who were using sign language and spoken language also led to better spoken language skills (e.g. Connor, Hieber, Arts, & Zwolan, 2000). Similarly, we could not determine whether early exposure to Sign Language played a role in post-implant reading comprehension.

A third limitation was the inappropriateness of the assessment instrument we used to evaluate the contribution of morpho-syntactic competence (Written Language Test for Deaf Children) to reading comprehension. The test involved multiple choice cloze tasks with written sentences and proved to be a measure of reading comprehension skills. This explains the relatively strong emphasis on receptive vocabulary in this thesis. These observations do not preclude that morpho-syntax is an important language comprehension factor in reading comprehension.

Practical implications

This study showed that CIs increased the opportunities of profoundly deaf children to reach a level of proficient literacy. Although their language development and reading skills still lagged behind those of children with normal hearing, the better text comprehension after cochlear implantation will be very advantageous to their future academic attainments and participation in society. These issues are among the main hopes of parents when they become involved in the process of cochlear implantation. Their aim with this invasive device is to enlarge the likelihood that their deaf child will develop spoken language and intelligible speech. Parents also wish to utilize the latent capacities of their child, for example, placement in more challenging educational settings. In the development of spoken language, an important factor that influenced literacy was post-implant auditory speech perception. Our findings showed that these skills developed best in educational settings that (also) offered spoken language. We agree with Knoors (2006) that specifically in view of the invasiveness of the implant process, educational settings need to be adapted to provide an environment in which optimal use can be made of the highly innovative device. Access to auditory signals offers new opportunities and responsibilities in the education of deaf children. The development of several skills needs to be stimulated: auditory speech perception, auditory memory and spoken language. Enlargement of the child's vocabulary occurs a consequence of auditory access to spoken language, because words are learnt via explicit instruction and perhaps even via informal input. Another challenge in the education of CI recipients is to adapt their school programmes to the use of audition in the process of learning to read. The use of an implant enables children to use letter-to-sound correspondence and even provides access to phonology. Schools that receive deaf children with CIs are the ideal setting to facilitate these developments.

The diverging opinions about cochlear implantation require us to reflect on the practical implications of the results of our study. In our sample there was wide variability in post-implant performance. Furthermore there are children that do not receive CIs, for medical, audiological or cultural reasons. As Blume (2006) and Knoors (2006) stated clearly, the responsibility of people involved in the care and education of deaf children extends to the whole group. We agree that decisions about the benefit in one subgroup of children should not put another subgroup at a disadvantage.

Despite excellent hearing rehabilitation, even the CI recipients who develop good auditory speech perception skills can never become children with normal hearing. Damen et al. (2006) found that according to the teachers, children with CIs are performing reasonably well in mainstream education. However, their communication skills were lagging. This finding is in agreement with observations made in a study by Isarin (2006). She reported that children with CIs were unable to absorb all the informal information generated in mainstream class room situations. Knoors (2006) concluded that in this respect, the educational approach to deaf children should remain bilingual and focused on the hearing society and the Deaf culture, because there would be no valid arguments to make changes. In a similar vein, Wever (2002) stated that in his opinion, the benefits of cochlear implantation did not justify neglecting the Deaf Culture and SLN. His conclusions were based on interviews with the parents of children who received their implants in the early 1990s. We stress that the cultural and social aspects of the Deaf Culture are valuable to all deaf children and participation in the Deaf Culture should not be in contradiction with the use of a cochlear implant. First, communication in sign language can be established relatively early in young deaf children, before they are eligible for a CI. These (sign) communicative skills will also be beneficial to the development of the child after implantation. Furthermore, contact between the parents of deaf children and deaf adults with and without CIs uncovers information that cannot be obtained from Implant Centre staff. The same holds for contacts between deaf children/adolescents with CIs and their deaf peers with and without CIs (Vermeulen, Langereis, Hoekstra & Van den Broek, 2007).

Based on the recent results of cochlear implantation, we advocate a more flexible and pragmatic approach to children with implants than that presently employed. We would also like to stress that use has to be made of the full individual potential of each deaf child to promote his/her well-being. There is urgent need for specific tailoring in the education. Future developments in the field of cochlear implantation, e.g. early implantation, bilateral implantation and cochlear implantation in multi handicapped children, will increase the variability in outcomes. In some children, focus on the development of spoken language will be best, whereas in others, a bi-lingual approach will be more appropriate. It should become possible to make flexible and reversible exchanges between these choices should be facilitated. In our opinion, such issues underline the need to develop special (long-term) programmes that address the needs of children with CIs. In mainstream education this can include activities for children with implants, creating opportunities for them to meet other deaf children and organising Sign Language courses. In deaf education more emphasis could be placed on the development of spoken language.

If such differentiated and pragmatic guidance does not become available in deaf education, we expect that the parents of deaf children with implants will continue to focus on mainstream education and as a consequence perhaps even reject valuable aspects of the Deaf Culture. On the other hand children with CIs in deaf education might not develop their full potential to participate in hearing society as a consequence of lack of stimulation of development of spoken language. We consider it the joint responsibility of teachers (for the deaf), parents and Cochlear Implant teams to devise *differentiated*, individual, guidance programmes. The above demonstrates clearly that in the management of children with a CI, the task of Cochlear Implant Centres reaches far beyond the achievement of maximum speech recognition results with a CI. Providing the correct care and supervision for a child with a CI, also in the long-term, is so complex that it must be safeguarded at specially equipped CI centres. This care and supervision must also be based on scientific data from these university centres.

Conclusion

This research showed that profoundly deaf children with CIs had better reading skills than deaf children without CIs. Furthermore, we verified a link between auditory speech perception and reading comprehension in a hypothesized causal chain. The relatively high level of reading comprehension in the deaf children with CIs could for a large part be attributed to the post-implant development of receptive vocabulary that in turn, was associated with their improved post-implant auditory speech perception abilities. These findings indicate that the use of a cochlear implant provided greater access to spoken language and enabled the children to achieve relatively high reading comprehension levels.

Nederlandse samenvatting en conclusie

Het begrijpend lezen van dove kinderen met conventionele hoorapparatuur is in veel studies buitengewoon beperkt gebleken. De beschikbaarheid van cochleaire implantaten (CI) bracht de verwachting met zich mee dat het begrijpend lezen van dove kinderen zou kunnen worden verbeterd, als gevolg van de (auditieve) waarneming van gesproken taal. Tot op heden was het verband tussen verbeterde auditieve spraakperceptie ten gevolge van cochleaire implantatie en beter tekstbegrip echter nog niet aangetoond.

Beschrijving van de studie en discussie

Deze studie was gericht op evaluatie van het begrijpend lezen van dove kinderen met een CI. Verder is onderzocht hoe het spraakverstaan na cochleaire implantatie het begrijpend lezen beïnvloedt. Het Simple View of Reading model (Hoover & Gough, 1990) vormde het kader voor onze analyses. In dit model wordt begrijpend lezen gezien als het product van twee componenten: decodeervaardigheid en (gesproken) taalbegrip. We onderzochten daarom het verband tussen het begrijpend lezen en decodeer- en taalbegripvaardigheden na implantatie. Onze verwachting was dat de ten gevolge van implantatie verbeterde auditieve spraakperceptie zowel de decodeervaardigheden als het begrip van gesproken taal zou verbeteren, resulterend in een hoger niveau van begrijpend lezen.

Beschrijving van de studie

Deze thesis bestaat uit drie empirische hoofdstukken. In Hoofdstuk 2 zijn het begrijpend lezen en de decodeervaardigheden (visuele woordherkenning) van dove kinderen met en zonder cochleair implantaten onderzocht en vervolgens vergeleken met die van horende kinderen. In het eerste deel van Hoofdstuk 3 is de ontwikkeling van het spraakverstaan na cochleaire implantatie beschreven en is de associatie met leesvaardigheden onderzocht. Vervolgens is in het tweede deel van Hoofdstuk 3 de ontwikkeling van taalvaardigheden na cochleaire implantatie beschreven en is ook de associatie met leesvaardigheden bestudeerd. Bovendien is de associatie tussen de auditieve en de taalvaardigheden bestudeerd. Daarbij is ook onderzocht wat de effecten van omgevings- en audiologische factoren op de ontwikkeling van deze vaardigheden zijn. Ten einde inzicht te krijgen in de richting van de associaties tussen auditieve spraakperceptie en begrijpend lezen, is een model van deze relaties geconstrueerd en getest in Hoofdstuk 4.

Er werkten 50 dove kinderen en adolescenten (tussen 7 en 22 jaar oud) die een CI gebruiken aan deze studie mee. De duur van hun implantaatgebruik varieerde van 3 tot 11 jaar. De groep bestond uit 25 jongens en 25 meisjes, met horende ouders. De kinderen kwamen uit alle delen van Nederland en volgden onderwijs op scholen die door het land verspreid lagen. Voorafgaand aan implantatie (pre-implantatie) volgde 74% van de kinderen speciaal onderwijs op scholen voor doven. De prestaties van de kinderen met CI werden vergeleken met die van dove kinderen zonder implantaten en met die van horende kinderen.

Het begrijpend lezen van dove kinderen met cochleaire implantaten

In Hoofdstuk 2 is het begrijpend lezen van dove kinderen met CI vergeleken met dat van dove kinderen zonder CI en dat van horende kinderen. Het begrijpend lezen van dove kinderen met CI was beter dan dat van dove kinderen zonder CI. Toch was het begrijpendleesniveau van kinderen met CI nog lager dan dat van horende kinderen. Gemiddeld presteerden ze nog 3 tot 4 standaarddeviaties onder het gemiddelde van horende klasgenoten. Ten behoeve van dit onderzoek werden wij in de gelegenheid gesteld gebruik te maken van data van dove kinderen zonder CI, die verzameld zijn door Wauters, in het kader van een grootschalige studie (Wauters, van Bon and Tellings, 2006). Deze referentiedata lieten zien dat het lezen van dove kinderen zonder CI aanzienlijk slechter was dan dat van horende kinderen. Dit was in overeenstemming met andere bevindingen (Traxler, 2000; Traxler & Allen, 1986). Naar onze mening is de betere leesvaardigheid van kinderen met CI het gevolg van het gebruik ervan, omdat er geen systematische verschillen tussen beide groepen dove kinderen konden worden aangetoond.

De associatie van begrijpend lezen met de twee componenten uit het Simple View of Reading model

Om te bepalen in hoeverre het begrijpend lezen verband hield met de twee componenten uit het Simple View of Reading model, zijn de decodeervaardigheden (Hoofdstuk 2) en het (gesproken) taalbegrip (Hoofdstuk 3) onderzocht.

Decodeervaardigheden werden onderzocht met lexicale decisie taken. De scores werden vergeleken met die van dove kinderen zonder CI, verzameld en geanalyseerd door Wauters (Wauters et al., 2006). In het voortgezet onderwijs lieten de kinderen met CI betere decodeervaardigheden zien dan de dove kinderen zonder CI. Er bleek geen verschil te zijn tussen de verdeling van de scores van de dove kinderen met CI en die van horende kinderen. Vanaf groep 6 waren de decodeervaardigheden van dove kinderen zonder CI echter slechter dan die van horende kinderen. De *z* scores van dove kinderen (met en zonder CI) behaald voor het decoderen weken minder ver af van de horende norm dan die voor het begrijpend lezen. De decodeervaardigheden verklaarden een groot deel van de variantie in de scores van het begrijpend lezen. Desondanks en ondanks de relatief goede decodeer vaardigheden van dove kinderen met CI lieten verdere analyses zien dat het verschil in begrijpend lezen tussen beide dove groepen, niet kon worden verklaard door het verschil in decodeervaardigheid.

Vervolgens is de *receptieve woordenschat* van de kinderen met CI onderzocht, als indicatie van de taalbegripcomponent. De receptieve taalleeftijdsequivalenten verklaarden een substantieel deel van de variantie in de scores van het begrijpend lezen.

Bij dove kinderen met CI bleek, net zoals voor horende kinderen, decodeervaardigheid op zich niet voldoende voor het begrip van geschreven tekst. Zoals verwacht was in elk geval de hier onderzochte taalbegripcomponent, receptieve woordenschat, van invloed op het begrijpend lezen van dove kinderen met CI.

Het verband tussen begrijpend lezen en verbeterde auditieve vaardigheden

Om de associatie tussen het verbeterde spraakverstaan (auditieve spraak perceptie) en het begrijpend lezen vast te stellen is eerst de ontwikkeling van het spraakverstaan na implantatie onderzocht. Het spraakverstaan van de kinderen was voor implantatie op het niveau van dove kinderen zonder bruikbaar restgehoor. Na implantatie verbeterden deze vaardigheden tot een niveau dat aanzienlijk beter was dan dat van dove kinderen met dergelijk hoorverlies die geen CI gebruiken. Na 36 maanden CI gebruik waren alle kinderen in staat geluiden in het spraakgebied te detecteren en herkenden gemiddeld 72% van de fonemen van auditief aangeboden monosyllaben. Omdat deze kinderen, ondanks langdurige training met conventionele hoorapparatuur, niet tot spraakverstaan kwamen beschouwen wij deze verbetering als een direct gevolg van cochleaire implantatie. Daarnaast vonden wij dat deze verbeterde auditieve spraakverstaanscores een sterke associatie vertoonden met de receptieve woordenschat. De resultaten van de analyses in Hoofdstuk 2 en 3, die een interveniërende rol lieten zien van receptieve woordenschat in het verband tussen het begrijpend lezen en het spraakverstaan waren het uitgangspunt voor de Structural Equation Modelling in Hoofdstuk 4. Er is een model geconstrueerd en getest waarin deze veronderstelde causale verbanden tussen spraakverstaan, via receptieve woordenschat en begrijpend lezen werden gespecificeerd. De fit indices voor dit model lieten een acceptabele fit zien. Dit model was opgebouwd uit twee minder complexe deelmodellen: een *tekstbegrip* submodel en een *auditieve voorwaarden en post-implant ontwikkeling* submodel. In het tekstbegrip submodel zijn de relaties van begrijpend lezen met decodeervaardigheid en met receptieve woordenschat, gebaseerd op het Simple View of Reading model, gespecificeerd. Beid componenten verklaarden, zoals aangegeven aanzienlijke delen van de variantie van de begrijpendleesscores. In het auditieve voorwaarden en post-implant ontwikkeling submodel waren is de relatie tussen spraakverstaan en receptieve woordenschat gespecificeerd. Een grote receptieve woordenschat was geassocieerd met beter spraakverstaan na implantatie een jaar eerder gedurende de follow-up.

Zoals aangetoond in Hoofdstuk 3 en 4 werd het spraakverstaan mede beïnvloed door audiologische en etiologische factoren. Het is bekend dat een langere periode van auditieve deprivatie (duur van doofheid) tot implantatie heeft een negatief effect op het spraakverstaan na implantatie. Bij congenitaal dove kinderen is dit effect sterker dan bij kinderen die op latere leeftijd doof worden (zie Par. 3.3.1). Zowel de leeftijd van doof worden als de leeftijd ten tijde van implantatie en hun interactie beïnvloeden de verwerkingsmogelijkheden van het auditieve systeem. De congenitaal dove kinderen die op latere leeftijd een CI kregen behaalden lagere spraakverstaanscores. Een andere factor van belang was de mate waarin het kind gesproken taal kreeg aangeboden. De Structural Equation Modelling analyses lieten zien dat kinderen die de eerste twee jaar na implantatie in reguliere settings onderwijs volgden, 24 maanden na implantatie beter spraak konden verstaan dan kinderen in settings voor speciaal onderwijs (Par. 4.5).

We concluderen uit onze gegevens en het geconstrueerde model dat we een verband tussen het verbeterd spraakverstaan na cochleaire implantatie en het relatief goede leesniveau na implantatie hebben gelegd. Dit verband is de interveniërende rol van verbeterde woordenschat na implantatie. Hieronder volgt een discussie van de beschreven resultaten.

Discussie

De belangrijkste bevinding uit dit onderzoek is dat het begrijpend lezen van dove kinderen met CI beter was dan dat van dove kinderen zonder CI. Het niveau van kinderen met CI was echter nog steeds lager dan dat van horende kinderen en het verschil dat wij waarnamen was groter dan hetgeen in enkele andere studies is gevonden. Geers (2003) vond dat 50% (van 181 kinderen van 8 tot 9 jaar oud) binnen 1 *SD* van het gemiddelde van horende kinderen scoorden, terwijl in een studie van Spencer, Barker and Tomblin (2003) 10 van de 16 kinderen (63%) binnen die range scoorde. Het verschil tussen de bevindingen in het onderhavige onderzoek en andere gegevens in de literatuur kunnen een gevolg zijn van groepskenmerken of van taakgerelateerde factoren. Mogelijke gevolgen van groepskenmerken worden verder besproken in het deel beperkingen van het onderzoek. Verschillen als gevolg van de (lees)taak die gebruikt is voor de evaluatie kunnen verband houden met het feit dat in het huidige onderzoek het begrijpend lezen is getest met behulp van een vraag-antwoord taak (Aarnoutse 1996). Deze taak bestaat uit het stillezen van korte verhaaltjes waarover multiple-choice vragen moeten worden beantwoord. Dit type taak doet een beroep op andere onderliggende vaardigheden dan cloze-taken (waarbij ontbrekende delen van woorden of zinnen moeten worden ingevuld). Het begrijpend lezen en de woordherkenning van de onderzoeksgroep kunnen we bijvoorbeeld niet vergelijken met de resultaten van Geers (2003) omdat in dat onderzoek een gecombineerde score werd vermeld. De visuele woordherkenning van de onderzoeksgroep in de huidige studie was relatief goed in vergelijking met het begrijpend lezen. Dit relatief goede decoderen kan de gecombineerde score in het onderzoek van Geers (2003) positief hebben beïnvloed.

Een eerste verwachting was dat het betere leesniveau van de onderzoeksgroep met CI (deels) een gevolg zou zijn van verbeterde decodeervaardigheden na implantatie. De toegenomen mogelijkheid om gesproken taal te verstaan zou het gebruik van grafeem-foneem correspondenties en van fonologische processen in het decoderen van tekst kunnen faciliteren. Deze decodeerstrategie voor het omzetten van letterreeksen in betekenis is efficiënt gebleken voor horende lezers. Zelfs bij slechthorende kinderen met relatief milde gehoorverliezen bleek beter spraakverstaan verband te houden met het gebruik van fonologische processen en betere leesvaardigheid (Leybaert, 1993; Perfetti & Sandak, 2000). Zoals beschreven in Paragraaf 3.4.1, hadden de dove kinderen met CI toegang tot fonologie bij het lezen van woorden. Dit betrof een lexicale decisie taak waarbij beoordeeld moest worden of gedrukte woorden wel of niet correct waren. De items bestonden uit bestaande woorden, homofonen (fonologisch correcte non-woorden) en pseudo woorden (non-homofonen). De resultaten lieten verrassend genoeg zien dat de kinderen gevoelig waren voor de fonologische structuur van geschreven woorden; de reactietijden voor de beslissing dat een homofoon niet bestaand was, waren langer dan de tijd die nodig was voor dezelfde beslissing betreffende pseudo woorden. Tegen de verwachting in vonden we geen associatie van visuele woordherkenning met de fonologische tekst decodeervaardigheden. Dit komt overeen met een andere onverwachte bevinding uit ons onderzoek, dat er geen verband aangetoond kon worden tussen spraakverstaan en decodeervaardigheid. De afwezigheid van een associatie van visuele woordherkenning met fonologische tekst decodeervaardigheid is mogelijk een gevolg van de relatief hoge leeftijd en goede decodeervaardigheden van de kinderen uit de onderzoeksgroep. In het proces van het leren lezen (bij jongere kinderen) kan wellicht wel een dergelijke relatie worden gevonden. De decodeervaardigheden van de kinderen met CI lagen binnen het 95% betrouwbaarheidsinterval van horende kinderen, bovendien waren ze beter dan deze van dove kinderen zonder CI in het voortgezet onderwijs. Er is vaker goede visuele woordherkenning van dove kinderen (zonder CI) gerapporteerd (e.g. Burden & Campbell, 1994; Beech & Harris, 1997; Wauters et al., 2006). Het niveau van de decodeervaardigheden kon het verschil in begrijpend lezen tussen de dove kinderen met en zonder CI niet verklaren. Dit werd voor kinderen zonder CI eveneens gemeld door Wauters et al. (2006). Ook Merrills et al. (1994) vonden dat visuele woordherkenning slechts een deel van de leesproblemen van dove kinderen zonder CI konden verklaren. Andere verklarende factoren werden besproken door Marschark en Harris (1996) en door Musselman (2000). Zij beargumenteerden dat, los van de decodeervaardigheid, problemen in de woordenschat en syntax een rol zouden spelen bij leesmoeilijkheden van dove kinderen. Volgens het Simple View of Reading model is decoderen inderdaad noodzakelijk maar op zichzelf niet voldoende om tot tekstbegrip te komen. Taalbegrip wordt eveneens als een belangrijke voorwaarde gezien. In dit onderzoek hebben we twee taalbegripcomponenten bestudeerd: receptieve woordenschat en morfo-syntax.

Ten tweede werd verwacht dat de taalbegripcomponent een deel van de variantie van de begrijpend leesscores van dove kinderen met CI zou verklaren. Gebleken is dat het begrijpend lezen inderdaad een sterke associatie met de receptieve woordenschat na cochleaire implantatie had. Een toename van de woordenschat na cochleaire implantatie werd niet alleen in de huidige studie maar ook in veel andere studies aangetoond (e.g. Svirsky, Stallings, Lento, Ying & Leonard, 2002; Tomblin, Spencer, Flock, Tyler & Gantz, 1999; Vermeulen et al., 1999). Verder was er een sterk verband tussen het spraakverstaan na implantatie en de omvang van de receptieve woordenschat een jaar daarna. De wijze waarop de toename van de woordenschat tot stand kwam kan uit dit onderzoek niet worden afgeleid. Het is echter hoogstwaarschijnlijk dat de auditieve waarneming van gesproken taal het voor dove kinderen met een CI mogelijk maakt woordbegrippen te leren via expliciete instructie. Veel van de kinderen uit de onderzoeksgroep volgden na implantatie onderwijs waarin relatief veel gesproken taal werd gebruikt. Het tweede onderzochte taalbegripaspect was morfo-syntax. De gemiddelde standaardscore voor de onderzoeksgroep was hoger dan die voor dove kinderen zonder CI. De gebruikte test bleek eveneens elementen van tekstbegrip te meten die ook met de begrijpendleestests werden vastgesteld. Dit bemoeilijkte de interpretatie van de hoge verklaarde variantie in begrijpendleesscores die verklaard werd door de scores van de morfo-syntax test. Veel auteurs hebben echter een verbetering van morfo-syntax ten gevolge van CI gebruik gerapporteerd (Spencer, Tye-Murray and Tomblin, 1998; Szagun, 2004; Svirsky et al., 2002). Bovendien zijn betere narratieve vaardigheden van kinderen met CI gevonden (Nikolopoulos, Dyar, Archbold, & O'Donoghue, 2004) en werd predictieve waarde van deze vaardigheden voor het begrijpend lezen gemeld. Het goede tekstbegrip van onze onderzoeksgroep wordt derhalve naar alle waarschijnlijkheid mede positief beïnvloed door hun vaardigheden op morfo-syntactisch gebied.

De twee componenten, decodeervaardigheid en taalbegrip, (en hun interactie) gedefinieerd door het Simple View of Reading model, die bestudeerd werden in dit onderzoek, verklaarden samen 59% van de variantie in begrijpend leesscores. Het grootste deel 48% werd verkaard door decodeervaardigheid. Receptieve woordenschat verklaarde 11% van de variantie. De totaal verklaarde variantie is vergelijkbaar met de in de literatuur vermelde waarden voor horende kinderen (e.g. Gough, Hoover & Peterson, 1996). In onze analyses werd alleen receptieve woordenschat meegenomen als taalbegripcomponent. Indien meerdere aspecten van taalbegrip zouden zijn betrokken in de analyses zou de verklaarde variantie wellicht kunnen toenemen. Een argument hiervoor is dat de SEM analyses in Hoofdstuk 4 lieten zien dat leeftijd, naast de taalfactoren, een belangrijke factor is voor het begrijpend lezen. Leeftijdsgerelateerde factoren zoals achtergrond kennis en metalinguïstische kennis zijn wellicht belangrijke factoren in het tekstbegrip van dove kinderen met CI. Concluderend blijkt het Simple View of Reading model toepasbaar voor het verklaren van de variantie in de begrijpend leesscores van dove kinderen met CI.

De toegang tot gesproken taal bleek een belangrijke factor voor de ontwikkeling van het spraakverstaan na implantatie, en daardoor voor de (gesproken) taalontwikkeling en het begrijpend lezen. Zoals Geers (2006) stelt is het mogelijk dat juist kinderen met betere taal en leesvaardigheden het meest waarschijnlijk in het regulier onderwijs zullen worden geplaatst, waardoor de betere prestaties op die gebieden bij kinderen in het regulier onderwijs een bias kunnen vertonen. In onze onderzoeksgroep was dit naar onze mening niet het geval. Voorafgaand aan cochleaire implantatie volgde 4% van de kinderen regulier onderwijs en 96% speciaal onderwijs. Na twee jaar CI gebruik volgde 35% onderwijs in een reguliere setting. Van de kinderen die in het regulier onderwijs werden geplaatst kwam 32% van een school voor slechthorende kinderen (10% van die kinderen was daarheen verwezen vanuit tweetalig dovenonderwijs). Er werd 63% geïntegreerd in het regulier onderwijs vanuit de enige orale school voor doven in die tijd. Ten slotte werd slechts 5% vanuit het tweetalige dovenonderwijs naar het reguliere onderwijs verwezen. Hieruit is af te leiden dat de keuze voor plaatsing in het regulier onderwijs vooral gebaseerd was op culturele of geografische factoren. Verder kunnen we stellen dat de overgrote meerderheid van de kinderen die in het reguliere onderwijs geplaatst werd ook in het speciaal onderwijs daaraan voorafgaand relatief veel gesproken taal kreeg aangeboden.

Beperkingen van deze studie

Een eerste beperking van deze studie is erin gelegen dat de resultaten ervan niet zondermeer gegeneraliseerd kunnen worden naar die van kinderen die nu en in de toekomst CI zullen gebruiken. Hoewel het leesniveau van de onderzoeksgroep beter was dan dat van dove kinderen zonder CI, waren de resultaten, zoals eerder aangegeven, minder gunstig dan in andere onderzoeken. Een belangrijke oorzaak hiervoor was de ongunstige audiologische uitgangspositie van de kinderen die aan de huidige studie deelnamen. De onderzoeksgroep bestond uit kinderen die tussen 1990 en 1999 een implantaat kregen in Universitair Medisch Centrum St Radboud Nijmegen. De klinische criteria die indertijd golden zijn momenteel niet meer van toepassing. Bij de kinderen uit de onderzoeksgroep was er sprake van totale doofheid zonder bruikbaar restgehoor (in tegenstelling tot de ernstige slechthorende kinderen die nu ook in aanmerking komen voor CI). Verder was de duur van doofheid tot implantatie voor de onderzoeksgroep lang, in het bijzonder voor congenitaal dove kinderen. Bovendien gebruikte een deel van de kinderen die deelnamen de wat oudere en minder gesofisticeerde M-Peak codeerstrategie (Geers, 2003). Deze factoren vormen een minder optimale voorwaarde voor het ontwikkelen van spraakverstaan na implantatie. Omdat momenteel de leeftijd bij implantatie aanzienlijk lager is dan die van de onderzoeksgroep en als gevolg van toepassing van nog geavanceerdere codeerstrategieën ligt het in de lijn der verwachting dat de auditieve vaardigheden, de taalvaardigheden en het begrijpend lezen van kinderen met CI in de toekomst nog verder kunnen verbeteren dan in de huidige studie is aangetoond.

Een tweede beperking van deze studie is dat we geen conclusies kunnen trekken betreffende de invloed van het gebruik van gebaren op de leesvaardigheid van de kinderen. Het grootste deel van de onderzoeksgroep beheerste geen (ondersteunende) gebaren. Begrip van gesproken taal bleek sterk samen te hangen met tekstbegrip. Het taalniveau in Nederlandse Gebaren Taal kan evenzeer geassocieerd zijn met tekstbegrip. Onder andere Connor, Hieber, Arts, & Zwolan (2000) hebben aangetoond dat bij kinderen die op jonge leeftijd een CI kregen en die zowel gebaren als gesproken taal gebruikten de gesproken taal zich goed ontwikkelde. De rol van vroegtijdig gebarenaanbod in de communicatie met jonge dove kinderen op de latere leesontwikkeling is in het bestek van de huidige studie evenmin onderzocht.

Ten slotte moet vastgesteld worden dat het onderzoeksinstrument dat gebruikt is om de bijdrage van morfo-syntactische vaardigheden aan het begrijpend lezen te bepalen minder geschikt was voor dat doel. De test, die multiple-choice cloze taken in gedrukte zinnen bevatte, bleek ook een maat te zijn voor het tekstbegrip. Dit verklaart de relatief grote nadruk die de receptieve woordenschat had in dit onderzoek. Dit sluit echter niet uit dat morfo-syntax een belangrijke factor in het lezen is en dat cochleaire implantatie hierop invloed heeft. Verder onderzoek op dit gebied is zeker zinvol.

Praktische implicaties

In dit onderzoek is aangetoond dat het gebruik van een CI tot betere mogelijkheden leidt om tot geletterdheid te komen voor dove kinderen, dan het gebruik van conventionele (of geen) hoorapparatuur. Hoewel de gesproken taal en de leesvaardigheid van de onderzoeksgroep nog achter lagen op die van horende kinderen is de betere geletterdheid een belangrijke factor voor betere participatie in het onderwijs en in de (horende) samenleving. Juist dat aspect was voor veel ouders een van de belangrijkste redenen om hun kind aan te melden voor cochleaire implantatie. Met de keuze voor cochleaire implantatie beoogden zij de mogelijkheden tot ontwikkeling van gesproken taal en verstaanbare spraak te bevorderen en de mogelijkheden voor het volgen van onderwijs te vergroten. De ouders vonden dat met name in het onderwijs de benadering beter afgestemd zou moeten worden op de ten gevolge van cochleaire implantatie toegenomen mogelijkheden van hun kinderen. Een belangrijke factor in de ontwikkeling van gesproken taal, die de geletterdheid bevordert, was de ontwikkeling van het spraakverstaan na implantatie. Onze bevindingen wezen uit dat deze vaardigheden zich het best ontwikkelden in onderwijssettings waar (ook) gesproken taal werd aangeboden. Zoals beargumenteerd door Knoors (2006) is het juist het ingrijpende karakter van cochleaire implantatie dat de noodzaak van aanpassingen binnen het onderwijs ten behoeve van optimalisering van het profijt ervan met zich brengt. De toegenomen auditieve vaardigheden bieden nieuwe mogelijkheden en taken voor het onderwijs; De ontwikkeling van het spraakverstaan, het auditief geheugen, fonologische vaardigheden en andere aspecten van de ontwikkeling van gesproken taal. Een andere nieuwe uitdaging voor het onderwijs aan dove kinderen is de mogelijkheid om het spraakverstaan in te zetten bij het leren lezen. Het leren van foneem grafeem koppelingen en het ontwikkelen van fonologische vaardigheden zijn belangrijke aspecten daarbij. Scholen (of ambulante begeleidingsdiensten) die kinderen met CI begeleiden hebben de mogelijkheid om deze ontwikkeling te faciliteren.

De uiteenlopende opvattingen aangaande cochleaire implantatie vragen ons inziens een reflectie op de hierboven beschreven praktische implicaties van dit onderzoek. Zoals Blume (2006) en Knoors (2006) duidelijk stellen, strekt de verantwoordelijkheid van degenen die betrokken zijn bij de begeleiding van dove kinderen zich uit over al deze kinderen. We vinden inderdaad dat men ervoor moet waken dat beslissingen ten behoeve van de ene subgroep niet negatief uitwerken voor een andere subgroep.

In onze onderzoeksgroep was sprake van een aanzienlijke variabiliteit in de mogelijkheden van de kinderen. Verder zijn er ook kinderen die geen CI krijgen, op grond van medische, audiologische of culturele overwegingen. Zelfs de kinderen die veel profijt hebben van een CI zijn geen normaal horende kinderen geworden. Het blijven kinderen met een ernstige beperking, die aparte zorg behoeven. Zoals beschreven door Damen et al. (2006), presteren dove kinderen met CI volgens hun leerkrachten behoorlijk goed in het regulier onderwijs. Uit de literatuur blijkt eveneens dat een aanzienlijke groep kinderen met CI binnen 1*SD* van het horende gemiddelde op gestandaardiseerde taaltoetsen presteert. Damen meldt echter ook dat hun communicatie een wat zwakker punt blijft. Een dergelijke bevinding wordt ook gerapporteerd door Isarin (2006). Zij stelt dat kinderen met CI nog veel informatie missen in de schoolsituatie. Knoors (2006) concludeert in dit opzicht dat er geen valide argumenten zouden zijn om de benadering in het onderwijs aan dove kinderen nu te wijzigen, dat wil zeggen, dat het onderwijs tweetalig moet blijven met een focus op zowel de horende als de Dovencultuur. Wever (2002) gaf eveneens aan dat naar zijn mening op basis van de tot dan toe bekende resultaten van cochleaire implantatie de voordelen die de Dovencultuur en NGT brengen, niet konden worden losgelaten. Wevers onderzoek betrof overigens (ouders van) kinderen die begin jaren negentig implantaten kregen. Ook wij willen in deze reflectie benadrukken dat de culturele en sociale aspecten van de Dovencultuur waardevol zijn voor alle dove kinderen en dat participatie aan deze cultuur het gebruik van een CI niet uit zou moeten sluiten en omgekeerd. Ten eerste, omdat voor jonge dove kinderen reeds in een vroeg stadium gebarentaal gebuikt kan worden voor het op gang brengen van de communicatie, al voordat een implantaat beschikbaar is. Deze communicatieve vaardigheden zijn ook van belang wanneer een kind een CI gaat gebruiken. Verder zijn contacten van ouders van jonge dove kinderen met dove volwassenen (met en zonder implantaat) en met andere ouders van dove kinderen belangrijk omdat dit hen van informatie voorziet die gebaseerd is op persoonlijke ervaringen en derhalve niet door professionals kan worden geboden. Dat geldt ook voor contacten tussen dove kinderen/adolescenten met CI en hun dove leeftijdsgenoten met en zonder CI (Vermeulen, Langereis, Hoekstra & Van den Broek, 2007).

Op basis van onze eigen en andere recentere gegevens pleiten wij voor een meer flexibele en pragmatische benadering in de begeleiding van dove kinderen met een CI dan op dit moment geboden wordt. We benadrukken daarbij dat voor het welzijn van een kind zijn of haar individuele potentieel moet worden benut. Er is daarom behoefte aan meer individuele keuzes in het onderwijs aan dove kinderen. De toekomstige medisch/technische ontwikkelingen (vroege implantatie, tweezijdige implantatie en cochleaire implantatie bij kinderen met meervoudige beperkingen) zullen de spreiding in de resultaten alleen maar vergroten. Vanuit dat oogpunt stellen wij dat voor sommige kinderen (en gezinnen) een benadering gericht op de ontwikkeling van gesproken taal het beste zal zijn, terwijl voor anderen een twee-talige benadering meer geschikt zal zijn. Deze keuzes zouden flexibel en omkeerbaar moeten zijn. Naar onze mening onderstreept dit het belang van het opzetten van speciale (lange termijn) programma's gericht op de begeleiding van kinderen met een CI.

Wanneer een dergelijk gedifferentieerd en pragmatisch aanbod niet beschikbaar komt in het dovenonderwijs ligt het in de lijn der verwachting dat ouders van dove kinderen met CI zich meer gaan richten op het regulier onderwijs met mogelijk zelfs afwijzing van waardevolle aspecten van de Dovencultuur als gevolg. Aan de andere kant zullen kinderen met CI in het dovenonderwijs met slechts een beperkt aanbod van gesproken taal onvoldoende mogelijkheden krijgen om ten volle profijt te hebben van hun implantaat en dientengevolge beperktere mogelijkheden om optimaal te participeren in de horende cultuur. Ons inziens is het een gezamenlijke verantwoordelijkheid van de Cochleaire Implant Centra, de betrokken onderwijsinstellingen en de ouders om gedifferentieerde individuele benaderingen te realiseren.

Het bovenstaande maakt duidelijk dat de taak van Cochleaire Implant Centra in de begeleiding van het kind met een CI verder strekt dan het behalen van een maximaal resultaat ten aanzien van het spraakverstaan met een CI. De zorg en begeleiding van een kind met CI is, ook op lange termijn, dermate complex dat deze gewaarborgd dient te zijn in speciaal hiertoe toegeruste Cochleaire Implant Centra. Deze zorg en begeleiding dienen voorts gebaseerd te zijn op de wetenschappelijke gegevens van deze universitaire centra.

Conclusie

Uit het onderhavige onderzoek blijkt dat dove kinderen met een cochleair implantaat (CI) beter begrijpend lezen dan dove kinderen zonder CI. Verder is er een verband aangetoond tussen het spraakverstaan en het tekstbegrip van kinderen met CI. Gebleken is dat het relatief hoge niveau van begrijpend lezen van dove kinderen met CI een sterke associatie heeft met de receptieve woordenschat na implantatie, die vervolgens weer sterk beïnvloed wordt door het verbeterde spraakverstaan. Deze bevindingen geven aan dat de grotere mogelijkheden tot het waarnemen van gesproken taal als gevolg van het gebruik van een CI, de kinderen in staat stellen tot relatief goed tekstbegrip te komen.

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(Brel)

Wetenschappelijke publicaties

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Van Horen Zeggen, 41, nr. 4, december 2000, 4-9.

Curriculum Vitae

Anneke (Agnes Maria) Vermeulen is geboren op 31 augustus 1965 te Breda. In 1987 behaalde zij haar diploma logopedie-akoepedie aan de Hogeschool Heerlen. Vervolgens rondde zij in 1991 de licentiaatopleiding Logopedie aan de Katholieke Universiteit Leuven (België) met onderscheiding af. Vanaf 1992 verrichte zij als Junior Researcher onderzoek naar spraakverstaan van een gereduceerd akoestisch spraaksignaal, in het kader van een Europees onderzoeksproject (STRIDE). Verder was zij sinds begin 1992 betrokken bij het opzetten van een begeleidingstraject voor kinderen met een cochleair implantaat (CI) en coördineerde de begeleiding aan kinderen en volwassenen met CI tot 2006. In de periode 1993-1996 was zij tevens mede verantwoordelijk voor het verzamelen en analyseren van de onderzoeksresultaten bij de eerste twintig kinderen die in Nederland een CI kregen en de verslaglegging daarvan in het kader van het Ontwikkelingsgeneeskundeproject ‘Cochleaire Implantatie bij Kinderen’ in 1996. In de periode 2001 tot en met 2006 was zij naast haar klinische werkzaamheden bij CI, parttime gedetacheerd bij de Interfacultaire Werkgroep Taal en Spraakgedrag van de Radboud Universiteit, ten behoeve van het onderhavige proefschrift.

Zij is momenteel werkzaam als researcher en daarnaast als clinicus verantwoordelijk voor de taal- en gehoorsonderzoeken in de selectie en evaluatieprocedure bij kinderen met CI, binnen het Cochleaire Implant team verbonden aan de afdeling KNO van Universitair Medisch Centrum St Radboud te Nijmegen.

Anneke is moeder van Camiel en Veerle (zes en drie jaar oud). Samen met haar partner Paul en hun kinderen is zij woonachtig in Ravenstein.